VENTILATION IN MINES

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MINING ENGINEER

TRANSLATED FROM THE GERMAN

BY

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WITH THIRTY PLATES AND TWENTY-TWO ILLUSTRATIONS

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PREFACE.

THE high importance of a uniform and sufficient supply of fresh air for the life and health of the workers in mines, and indeed for the performance of the various operations therein, would seem to justify special treatment of this branch of the art of mining.

The Author's first idea was to undertake a translation of Theophil Guibal's work on Ventilation; but more than twenty years have elapsed since the death of that authority, during which period great progress has been made in the ventilation of mines; and, especially as opinions and knowledge have undergone considerable modification with regard to the dangerous gases occurring in mines, it proved necessary to amplify Guibal's work and bring it up to date. One point that required introduction was the matter of respiration and rescue apparatus. Another was the cooling of the workings, surrounding rock, and the air of the mine, this question having been brought to the front of late, in consequence of the ever-increasing depth of mining operations, and the accompanying rise in the rock temperature; to which must be added, in the case of coal mines, the increase in temperature due to the absorption of oxygen by coal at the ordinary temperature.

As is well known, continued exposure to high temperature is injurious to health, and, since the working efficiency of the miners is reduced in proportion as the pit temperature is increased, it is necessary to take steps to combat this unfavourable influence. Now the only way to do this effectually is to replace the usual, simple air ways by driving three, four, and more intake and return air ways in setting out the mine, thus considerably increasing the surface of contact between the air current and the gallery walls, reducing the velocity of the current, and prolonging the period of contact.

The individual ventilating and working sections must also be reduced in size, and the excessive length of the air ways avoided.

It will be evident that, in future, just as much care must be bestowed

on the provision of an ample supply of motive power for the efficient ventilation of a mine as has to be done in connection with the establishment of the necessary powerful engines for pumping and winding.

In this respect typical examples are afforded by existing installations at well-ventilated fiery pits—such, for instance, as that at the Hibernia pit, Gelsenkirchen, described by Behrens in his work on the Firedamp Problem.

The Author is only too conscious that the present work is lacking in completeness, and would be grateful for any corrections and supplementary information from experts interested in the matter, for insertion in a subsequent edition.

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VENTILATION IN MINES.

INTRODUCTION.

1. Mines are artificial subterranean cavities made for the purpose of recovering minerals, and as a rule their communication with the outer air is merely by means of a few narrow orifices, the consequence being that, where the underground workings are extensive, difficulties arise in connection with the introduction of fresh air and the removal of contaminated air.

The atmospheric air is of almost invariable composition everywhere, and contains 20·93 parts by volume of oxygen, 78·10 of nitrogen, 0·94 of argon, and 0·03 of carbon dioxide, small quantities of water vapour being always present up to saturation point. In the course of its ceaseless movement around the globe, the air carries on its waves a number of light, minute bodies, germs of plants and animals, mineral dust, gases resulting from the decomposition of plants and animals, or from combustion and respiration, smoke, and, in the vicinity of large towns, factories, and smelting works, various impurities, such as sulphur dioxide, metallic vapours, and the like; the amount and character of these extraneous admixtures influencing the suitability of the air for human respiration.

So far, however, as the ventilation of mines is concerned, these atmospheric impurities are devoid of importance, since, just in the same manner as river water laden with the refuse matters of large towns and certain factories quickly purifies itself, so these contaminating ingredients of the air are soon eliminated therefrom. Rain and dew carry down the floating solid particles and many gases, whilst the excess of carbon dioxide is removed by plants, especially extensive forests, with the collaboration of light, the carbon being retained and the oxygen liberated into the air again.

2. Consequently, though the air is exposed to various local modifications, its general composition will be found fairly constant, provided

the samples examined have not been drawn too near a source of contamination. It may therefore be concluded that, in the case of pit air, we have not to trouble ourselves with the question of how to restore the contaminated air of the mine to its original good condition, but all that has to be considered is how the same can be returned into the general mass of the atmosphere and replaced by pure air, in order to keep the pit air healthy and respirable. This object is effected with the aid of a ventilating current.

To produce such a current entails the exertion of force, or an expenditure of energy in overcoming resistances opposing the movement of the ventilating current. This must, however, be accomplished in such a manner as to ensure that all the spaces in the mine are traversed by this current, without injury to the health of the miners; moreover, an endeavour must be made to carry out the plan in the most economical manner, by suitably arranging the underground workings, diminishing the resistances, and suitably selecting the ventilating appliances.

3. The science of mine ventilation, which deals with the ways and means of providing a supply of fresh air to the pit, may be divided into the following five sections for treatment :—

I. The causes of the contamination of pit air, and the means of preventing the resulting dangers to the life and health of the miners.

II. The calculation of the amount of ventilating required to counteract the contamination.

III. The determination of the resistances opposing the flow of the ventilating current.

IV. The means of providing the necessary current of air.

V. The ways and means of utilising the air current to the utmost advantage and distributing it throughout the workings.

CHAPTER I.

CAUSES OF THE CONTAMINATION OF PIT AIR.

1. The causes of contamination in pit air are partly natural and spontaneous, partly artificial and due to the conditions of working.

In the first place, the air may be fouled by the exhaustion or consumption of the oxygen necessary to respiration; secondly, by the liberation or production of injurious gases; and thirdly, by the presence of finely divided particles of solid matter, such as coal dust, soot, and smoke.

The health of the miners is also prejudiced by an excessively high temperature in the pit air, especially when the same is saturated with water vapour and the current moves with such velocity as to produce an excessive draught.

Composition of the Air.

2. As already mentioned, atmospheric air contains 20·93 (21) parts by volume of oxygen and 79 parts of nitrogen (with 0·94 of argon). One cubic mètre of air weighs 1·2936 kilogrammes at 0° C. and 760 millimetres pressure.

The Oxygen of the Air.

3. The life-maintaining constituent, oxygen, the chemical symbol for which is O, has the specific gravity 1·1056 compared with air; 1 cubic metre weighs 1·430 kilogrammes.

Oxygen is a colourless, odourless, and tasteless gas, which enters into combination with all the elements except fluorine, and also combines with many compound bodies. Hence a considerable amount of oxygen is consumed in mines. According to the researches of Dr. Schondorf, in the mines at Saarbruecken, the consumption of oxygen by the miners, the horses, and the lamps in a pit amounts to only about one-seventeenth of the total consumption therein, the remainder being used up in the oxidation of coal and pyrites, by absorption into the rock, and by the putrefaction of the pit timbers.

The combination of oxygen with other substances is known as oxidation, and if the operation be accompanied by evolution of heat and light it is termed combustion.

Luminous combustion proceeds only in the case of gaseous bodies, or such solid or liquid bodies as are gasified by the heat generated during combustion; or again in the case of gaseous, combustible decomposition products. Other substances, *e.g.* carbon (coke), burn without flame, merely becoming incandescent on combining with oxygen.

Oxidation also occurs during respiration. Here the oxygen comes into contact with venous blood in the lungs, whereupon the carbon in the blood is oxidised into carbon dioxide (carbonic acid, CO_2), which is then exhaled.

Of late, oxygen has been prepared artificially, and is sold in the condensed form, which is administered for artificial respiration in many cases of disease, as also in the event of carbon monoxide (CO) poisoning. In the condensed state it is also used for charging the respiratory and rescue appliances employed when spaces filled with irrespirable gases have to be entered.

Until recently it was believed that suffocation necessarily ensued in the human subject on exposure to an atmosphere so poor in oxygen as to be incapable of supporting combustion in the ordinary sense. This has been shown to be incorrect by Dr. Haldane of Oxford, who was entrusted by the Home Office with the investigation of the causes and results of the colliery explosions at Tylerstown, Brancepeth, and Micklefield. His researches have thrown a great deal of new light on the effects of air poor in oxygen, and of the poisonous gases present in the afterdamp succeeding explosions of firedamp, as well as those in the fumes generated by pit fires.

4. When the oxygen content of inhaled air is gradually reduced, the respiration of the human subject is found to slightly decrease in depth on the percentage of oxygen falling to 12 per cent. At 10 per cent. of oxygen, breathing is accelerated, the respirations are deeper, and the lips turn pale blue. At 8 per cent. the face assumes a bluish-grey tinge, although no great uneasiness is so far manifested. Laboured panting first appears at 5 to 6 per cent., and is succeeded by unconsciousness, death finally occurring after a shorter or longer interval. When the inhaled air contains less than 1 to 2 per cent. of oxygen, unconsciousness supervenes after 40 to 50 seconds, without previous panting. Consciousness vanishes more rapidly than it does under water or in strangling, since not only is the patient deprived of a supply of oxygen, but that already in the lungs is immediately expelled by the violent breathing.

Loss of consciousness is followed by cramp, and respiration ceases. In the case of dogs or cats, the heart of the subject continues to beat for 2 to 8 minutes; but in the case of man this period would be of longer duration, it being apparently a general rule that the resistance to suffocation increases with the size of the organism. Dr. Haldane himself continued to inhale air containing only 0·7 per cent. of oxygen for half a minute without losing consciousness, whereas a mouse under the same conditions was seized with convulsions in 15 seconds, respiration ceasing almost entirely. So long as the beating of the heart continued, it was found easy to resuscitate the affected animal by means of artificial respiration. Sometimes this artificial respiration must be prolonged for a considerable time, since the injuries may be grave, in which case recovery is a slow process. It also happens that consciousness is not restored for some hours after the resumption of respiration, and in such event there is danger of a fatal result unless the patient be treated with extreme care and skill.

Great exertion in an atmosphere impoverished of oxygen to a certain extent may produce unconsciousness. Consequently such exertion must be avoided in the pit when the impoverishment of the air is manifested by the extinction of the lights. The flame of the miner's lamp goes out when the oxygen content of the pit air has receded to 17·6–17·1 per cent. The first quoted figure, 17·6 per cent., refers to a candle held upright, whereas when held horizontally it is not extinguished until the percentage has fallen to 17·1.

From the foregoing it follows that the extinction of lights in consequence of a lack of oxygen in the air does not imply danger to human life by suffocation, this danger not arising until the percentage of oxygen is much lower (below 7 per cent.).

NITROGEN.

5. NITROGEN (symbol N), the second chief constituent of the air, has no chemical action on mankind or animals. It is an inert gas, devoid of colour, smell, or taste; the specific gravity is 0·9731, and 1 cubic metre weighs 1·2553 kilogrammes.

The argon recently discovered in air by Lord Rayleigh and Professor Ramsay seems to resemble nitrogen in its properties, but it is still imperfectly known. The amount present in air is stated to be about 0·94 per cent.

OTHER CONTAMINATING GASES PRESENT IN PIT AIR.

6. The following gases escape in smaller or larger quantities from the fissures and pores in the rock, or are liberated in consequence of atmospheric influences, warmth, or mining operations:—

(a) Carbon dioxide, CO_2; density, 1·5240.	A cubic metre	weighs	1·9714	kilos.
(b) Carbon monoxide, CO; density, 0·968.	"	"	1·252	"
(c) Methane, or pit gas, CH_4; density, 0·558.	"	"	0·7218	"
(d) Pure hydrogen, H; density, 0·0693.	"	"	0·0896	"
(e) Sulphuretted hydrogen, H_2S; density, 1·191.	"	"	1·5407	"
(f) Sulphurous acid, H_2SO_3; density, 2·21.	"	"	2·859	"
(g) Water vapour; density, 0·624.	"	"	0·8072	"

(h) Various miasmatic gases resulting from the decomposition of organic matter; also certain metallic vapours, especially mercury.

7. With regard to the appearance, properties, and influence of these gases and vapours on animals and the human organism and on pit lights, the following observations may be made.

8. CARBON DIOXIDE is a colourless gas, with a prickling, faintly acid taste and smell, and is met with very extensively, both free and combined, in nature. In the vicinity of volcanic rocks it is often found issuing in abundance from the ground, *e.g.* at the so-called Dog's Grotto near Naples, the Dunsthoehle near Pyrmont, at the Bromthale in the Rhineland district, etc. As already mentioned, atmospheric air contains usually 0·03 to 0·04 per cent. of this gas; pit air generally a somewhat larger proportion. Small quantities are also found in all well and spring waters, and larger amounts in many mineral springs. Some coal seams contain carbon dioxide, *e.g.* those in the Haenichen Colliery near Dresden. On the other hand, firedamp is encountered in the same seam in the adjoining colliery belonging to Baron von Burgk, which is situated farther within the limits of the small Dresden coal basin; whereas the seam found in the Government colliery at Zankeroda, which is situated in the other wing of the basin, again contains carbon dioxide. Consequently, both here and in the Haenichen pit it is impossible, on account of the escape of carbon dioxide (chokedamp), to cut on the bottom of the seam; neither can the miners be allowed to remain singly in the working places, on account of the danger of stupefaction by the gas, which would be infallibly attended with fatal results.

In addition to that present, either free or combined with minerals, in nature, carbon dioxide is continually being produced from organic substances at the ordinary temperature by fermentation, respiration, decomposition, or putrefaction; in the first and last cases with the

collaboration of micro-organisms. It is also formed at higher temperatures by combustion.

Many kinds of coal and lignite, when brought into contact with air, undergo gradual oxidation, whereby carbon dioxide is formed in large quantities. The temperature of the coal slowly rises, and this may proceed so far that spontaneous ignition ensues. This gradual accession of temperature is also noticeable in working seams that are rich in pyrites and of considerable thickness, more especially when the pillars suffer compression and the coal is converted into dust, so that it presents a large surface to the air. On this account, large volumes of carbon dioxide are formed in old workings (goaf) of such seams, owing to the large quantity of coal dust left behind there.

Other sources of carbon dioxide in the pit are the miners' lamps, and the respiration of the men and any animals there. The amount produced in this way is, however, comparatively unimportant; so that a slight ventilating current would suffice to carry it away as soon as formed.

Another important source of carbon dioxide in the pit is the ignition of firedamp—a matter to which we shall revert later on. As carbon dioxide does not enter into any chemical combination with the blood, it cannot be regarded as a poisonous gas, though irrespirable and incapable of supporting life. Dr. Haldane, it is true, looks on CO_2 as exerting a poisonous action, because when present to the extent of 5 per cent. in inhaled air it rapidly causes death by suffocation, whereas a similar proportion of a natural gas, such as hydrogen or nitrogen, does not produce this result. This fact, which has been demonstrated by experiments with animals, is, however, explainable by the greater density of carbon dioxide, and by the circumstance that this gas is constantly produced in the lungs. Man is also suffocated when submerged in water, without any assumption being urged that this liquid is poisonous.

In any event, the action of carbon dioxide on the human organism is less injurious than it is generally assumed to be, the evil reputation it enjoys among miners being really due to the action of the hitherto insufficiently recognised carbon monoxide.

The first effects of the presence of carbon dioxide in air begin to manifest themselves when the proportion of this gas attains 3 to 4 per cent. At this stage the depth of the respirations is slightly increased, though without any resulting disturbance or injury to the organism; and animals that are kept for several weeks in such an atmosphere exhibit no unusual phenomena. The depth and frequency

of the respirations increase with the percentage of the gas; at 6 per cent. decided gasping occurs, accompanied by a slight pain in the forehead, this usually becoming somewhat worse on a return to a purer atmosphere. At 7 to 8 per cent. the oppression and panting become very painful, especially at the outset; but it is only when 10 per cent. is reached that the difficulty becomes severe. At a slight increase beyond this stage suffocation ensues, and the subject of the experiment loses consciousness, without—as tests on animals have demonstrated—there being any actual danger to life.

The effect of carbon dioxide on the light of lamps or candles seems to increase regularly in proportion as the amount of oxygen in the air decreases. According to Professor Clowes, the presence of 15 per cent. of carbon dioxide in the air causes the extinction of the flame; and the same result ensues when the air is mixed with 17 per cent. of nitrogen.

Dr. Haldane has demonstrated that a candle will continue to burn in a mixture containing 75 per cent. of carbon dioxide, provided the remaining 25 per cent. consists of oxygen. Since carbon dioxide, though not poisonous, is irrespirable, care is always necessary on entering a place where its presence is suspected; and such places should on no account be entered without a light. Owing to its greater density, this gas does not readily mix with air, but often collects, in a fairly pure state, in considerable quantity in low-lying spots, such as the bottom of shafts and wells and the floor of pit headings. If the lamp is suddenly extinguished on being gradually lowered from above to the gallery floor, a dangerous accumulation of carbon dioxide may be concluded, and caution is necessary. Shafts of wells may often be entered after water has been run in for some time, since this liquid carries air down with it, and displaces the carbon dioxide; or, again, the air may be set in action by quickly raising and lowering a bundle of brushwood or straw suspended by a rope. However imperfect these methods may appear, they are nevertheless able to do good service when it is a question of saving the life of some one who has been overtaken by the gas and has lost consciousness. Another plan recommended is to pour in milk of lime, since this absorbs the CO_2. If, however, these means should prove ineffectual, then attempts must be made to induce a ventilating current, as will be described later on.

9. Carbon monoxide is a colourless, tasteless, and inodorous, but combustible gas, and therefore extremely poisonous, even in small quantities. It is produced only at high temperatures, whereas the dioxide is formed at ordinary temperatures as well. When carbon dioxide is

passed over glowing charcoal it is reduced to CO, which latter burns with a blue flame on contact with the air, and is reconverted into carbon dioxide.

Many metallic oxides also suffer reduction when heated to incandescence with carbon, CO being formed. Consequently large volumes of this gas are produced in certain metallurgical processes, *e.g.* in blast furnaces. It is customary to say that carbon monoxide is formed by incomplete combustion, when the amount of oxygen present is insufficient to entirely consume a fuel to CO_2.

Somewhat large amounts of CO are also formed when gunpowder is exploded—this powder being, as is well known, a mixture of finely pulverised charcoal, sulphur, and saltpetre—especially when the powder is damp, or contains too small a proportion of saltpetre (below 78 per cent.), since in such event the amount of oxygen in this latter is insufficient for the complete combustion of the sulphur and carbon present. Consequently in such cases the poisonous CO and the still more poisonous sulphuretted hydrogen are formed. A considerable amount of carbon monoxide is associated with the dioxide in after-damp: the dangerous mixture of gases resulting from the explosion of firedamp, and the gasification and combustion of fine coal dust. It is also present in dangerous quantities (up to 2·75 per cent.[1]) in the fumes generated during the progress of pit fires.

A larger proportion of carbon monoxide is furnished by the combustion of coal than is the case with wood; this result being apparently due to the circumstance that with the former there is always a certain amount of glowing carbon, which presents an opportunity for the carbon dioxide to become reduced to monoxide. Illuminating gas, resulting from the distillation of coal, contains about 5 per cent. of the monoxide, and is therefore highly poisonous.

10. The reason for the poisonous action of carbon dioxide when breathed will now be more closely explained. When respiration is conducted in ordinary air the oxygen is absorbed through the lungs into the blood, and forms with the red blood corpuscles (hæmoglobin) an unstable chemical compound: this is conveyed by the circulation into the parts of the body where it can be utilised for the needs of the latter, namely, into the tissues. However, as was shown by Claude Bertrand, the hæmoglobin of the blood has a far (about 250 times) greater chemical affinity for carbon monoxide than for oxygen; and, so soon as it is saturated with CO to form carboxyglobin, it ceases to

[1] The characteristic smell of these fumes is due, not to the presence of carbon monoxide, but to smoke and distillation products (hydrocarbons, ammonia, etc.).

take up any further oxygen from the air. Consequently no oxygen finds its way into the tissues, and a fatal termination results, just as though the inhaled air contained little or no oxygen at all. It is thus evident that the disturbances produced in the organism by CO do not appreciably differ from those resulting from a deprivation of oxygen. If one remained for some time in an atmosphere containing 0·1 per cent. of CO, the blood would finally be equally saturated with CO and O. On returning to pure air a gradual elimination of CO from the blood ensues, inasmuch as it is probably converted into carbon dioxide. In pure oxygen the elimination proceeds five times as rapidly as in atmospheric air. So soon as the blood is saturated with 50 per cent. of CO all control over the limbs is lost, the sufferer is unable to move, and finally becomes unconscious. When the proportion of CO in the air reaches 0·1 per cent., then the blood cannot become saturated to a greater extent than 50 per cent., and no immediate danger to life ensues; but with 0·2 per cent. of CO in the air the saturation limit of the blood is increased to 67 per cent., the sufferer becomes unconscious, and death supervenes. The presence of 0·3 per cent. of CO is exceedingly momentous and dangerous.

It is also a matter of some importance to ascertain the interval elapsing between poisoning with CO and loss of consciousness therethrough. In order to approximately estimate this interval, it may be taken for granted that the blood of a full-grown man can absorb about 1·1 litre of CO and O before saturation. On the other hand, a man when at rest will inhale and exhale from 5·5 to 6·6 litres of air per minute. Furthermore, it has been shown by experiment that only 60 per cent. of inhaled CO is actually absorbed into the blood.

Now, if we assume the air to contain 0·1 per cent. of CO, the amount of this gas absorbed will average about 0·00396 litre per minute, and thus 4 hours and 36 minutes will elapse before 1·1 litre of CO is taken up into the blood. When the proportion of CO is 0·2 per cent. the time will be reduced to one-half, with 0·3 per cent. to one-third, and so on. The period will, however, be still further shortened when the individual has already spent some time in an injurious atmosphere, and has not since fully recovered. Moreover, when at work or in motion, a man inhales about three times as much air as when at rest, and in such case only about one-third the usual time will be required for the absorption of a given quantity of CO into the blood. With air containing 0·3 per cent. of CO the blood will be saturated with this gas in half an hour, and consciousness will be lost in quarter of an hour (semi-saturation). With 1 per cent. of

CO this will not take longer than 5 to 6 minutes, even supposing that the ill-ventilated place does not already contain other injurious gases or impoverished air, which will generally be the case in the pit.

11. The danger of entering headings laden with afterdamp containing CO, smoke, or products of combustion, must therefore be regarded as considerable, owing to the possibility of traversing a good distance therein before the action of the injurious gases becomes apparent, and that when this does occur the power to gain safety by retracing one's steps is lost. Hence, when the necessity arises for penetrating an atmosphere laden with carbon monoxide or smoke fumes, it is strongly advisable to keep a number of men in the rear, in a pure atmosphere, as a reserve for rendering immediate aid in case of need. Many lives have been saved in English collieries by the adoption of this precaution.

Again, before entering an ill-ventilated place, filled with smoke, the mouth and nose should always be covered with a damp cloth, to prevent, at any rate, the penetration of dust and smoke into the air passages and lungs, and the consequent hindrance to recovery.

12. When sojourning in air containing carbon monoxide, the condition of total helplessness is preceded by phenomena which should be very carefully observed, namely, giddiness, swelling of the veins in the forehead, a feeling of dulness in the limbs, weakening of the sight, and palpitation of the heart under the slightest exertion. These indications are very decided when the saturation of the blood has attained 25 to 30 per cent., and increase therewith. At 50 per cent. the limbs become very feeble and refuse their office, unconsciousness rapidly supervening. When the saturation by carbon monoxide reaches 79 per cent., death is inevitable. Moreover, the above indications are accompanied by very painful sensations. The crippling of the limbs is followed by a weakening of the senses, as under the influence of gradual suffocation.

When the percentage of CO attains 1 to 2 per cent., unconsciousness is quickly followed by cramp, just as in cases of suffocation through lack of oxygen. With a little under 1 per cent. of CO in the air, death approaches very quietly: this is evidenced by the condition observed in individuals who have been suffocated by a low percentage of carbon monoxide in pit air.

Those who have partly lost consciousness through the influence of CO, experience, for several days or even weeks after recovery, disturbances in health which may be very severe. Should the action of the poisonous gases have been more prolonged, recovery is doubtful, whatever the remedies applied. In any case it would be very protracted, and accompanied by pains demonstrating the great extent to which the blood has

been injuriously affected by the carbon monoxide, and how greatly the nervous system has suffered. The breathing and pulse are irregular; the temperature of the body rises to 39° C. and over. Every attempt to move the arms and limbs gives rise to muscular spasms and epileptic cramp. Even if the result is not fatal, prolonged illness is certain.

If, on the contrary, the period of unconsciousness has been merely of short duration, and the sufferer has been quickly brought into a pure atmosphere, recovery will generally ensue within a few hours. It is accompanied by violent headache, and also by nausea and vomiting. The disturbing effects will be greater in proportion as the sojourn in the poisonous atmosphere was prolonged.

Dr. Haldane ascertained, by personal experience, that exposure to an atmosphere containing even only 0·07 per cent. of CO was sufficient not merely to produce vertigo on the slightest exertion, but also to cause headache lasting for over 12 hours.

He also demonstrated by experiment that, after a strong poisoning with CO, it takes about 6 hours to free the blood from the poison; whereas, on the other hand, it has been determined that the combination between the red blood corpuscles and CO is so stable in the case of persons who have died from this cause, that the presence of CO can be proved by spectrum analysis after the body has lain twelve months in the grave. This proves that the living organism alone is in a position to eliminate the carbon monoxide absorbed during respiration. The means by which this is accomplished is, as already indicated, by conversion of the CO in the blood into carbon dioxide.

13. Carbon monoxide gains access to the blood solely in the breath, and not by absorption through the skin. The dark red colour of the blood is changed by the absorbed gas into a highly characteristic pale to rose-red shade. Those parts of the body where the colour of the blood can be observed through the skin, *e.g.* the lips, also assume a decidedly pale red coloration in cases of fatal poisoning by this gas, whereas in the event of death from other causes they turn a leaden grey or have a pallid look. By reason of this rose colour, the bodies of persons who have died from carbon monoxide poisoning look as though still in life.

The same pale red coloration due to CO poisoning is very decidedly apparent when the muscles are dissected. It may, however, happen that this coloration has again disappeared, if the sufferer remained unconscious for some time after inhaling the poisonous gas, instead of dying immediately. If in the interim the ventilating current has been restored and has carried away the poisonous gases, then the absorbed CO may have been eliminated from the blood, though the case terminated fatally all the

same. Instances of this kind have been frequently noted in English collieries.

The small proportions of CO required to produce a fatal result cannot be detected, either by the lamp flame or otherwise, since this gas does not form a flame cap unless present to the extent of at least 1 per cent. in the air. Chokedamp from fires, which also contains up to 3 per cent. of CO, usually exhibits, it is true, a peculiar burning smell; but this, as already mentioned, arises not from CO but from certain hydrocarbons, ammonia, etc.

A point that should be particularly borne in mind is that, CO being an inflammable gas, lamps are not extinguished by an atmosphere containing a fatal dose of this component. Such a gaseous mixture is not explosive until the proportion of CO attains over 15 per cent.

Means of Detecting CO in Air.

14. It is also a matter of great importance to have some means of reliably detecting the presence of CO in the air. It is already known that the blood of small animals is more quickly saturated with CO than is the case with man. It therefore follows that a mouse, for example, will more quickly exhibit the effects of carbon monoxide than a human subject; or, in other words, the condition of a mouse after a brief sojourn in an atmosphere containing a dangerous proportion of CO will be the same as that of a man after a longer exposure therein. The coefficient is about 20 for a man at rest.

Thus Dr. Haldane found that, with 0·4 per cent. of CO in the air, a mouse gave symptoms of illness after a sojourn of 1½ minutes, and became unconscious in 3 minutes; whereas the experimenter himself did not feel serious discomfort until half an hour had elapsed. This proportion of CO is present in the afterdamp succeeding firedamp explosions. and is frequently injurious to rescue-parties.

When one desires to enter a part of the pit laden with afterdamp or chokedamp, the mouse can be carried in a small cage, or inside a gauze from a safety lamp. For this purpose, a few mice should be kept in readiness in the engine-house or other suitable place.

On entering such contaminated air, the latter may be regarded as really dangerous from the moment when the test-mouse becomes incapable of motion and falls down unconscious.

15. So far as concerns the detection of CO in the blood of living human beings and corpses, this can be effected in the first place by spectrum analysis, and secondly by the difference between the colour

(dark red) of pure blood and the rose-red shade of blood containing this gas.

Spectroscopic Examination of CO in the Blood.

16. If a drop of the blood under examination be diluted with water, so that the two absorption bands of CO are perfectly visible in the spectroscope, the two bands will remain almost as decidedly visible after an addition of ammonium sulphide and gentle warming, if CO be present and the blood is saturated therewith. According to Dr. Haldane, however, this test gives unreliable results when the degree of saturation by CO in the blood is only 40 per cent. or less.

Colorimetric Examination of the Blood for CO.

The same authority states that better results are furnished by the second method, namely, the colorimetric test, which also enables the degree of saturation to be approximately gauged at the same time. The method of applying the test is as follows:—

As already mentioned, the blood of living mammals exhibits a more or less decided pale to rose-red colour when partly or completely saturated with CO. The only means of changing the dark red colour of pure blood into this paler tint is by the addition of a definite quantity of a 1 per cent. aqueous solution of carmine, which forms the reagent employed in the present test. A standard solution for comparison is prepared by making a 1 per cent. aqueous solution of pure blood, and saturating the same with CO by means of coal gas (which contains about 5 per cent.).

The blood under examination for CO is converted into a 1 per cent. aqueous solution and placed in a test-glass. To this solution is now added the 1 per cent. solution of carmine, run in drop by drop from a burette, whereupon it will gradually assume the rose-red tint of the standard check solution. The carmine solution having previously been standardised on a 1 per cent. solution of pure blood, so as to ascertain the quantity required to bring the latter to the same shade as the check solution, it is then possible to calculate the percentage of CO in the blood under examination. It is evident that, the larger the percentage of CO in the solution under examination, the smaller will be the amount of carmine solution required to bring it to the standard colour. If no addition is needed, and the test solution is already of the same shade as the check solution, then the blood in question is evidently saturated with CO. If, on the other hand, one-half the predetermined quantity of car-

mine solution is needed to bring the solution to standard, the saturation with CO is only 50 per cent., and so on.

Treatment of Victims of CO Poisoning.

17. It is clear that, in cases of CO poisoning, the main essential for securing the elimination of the CO from the blood is the administration of oxygen, and that consequently the victims must be carried into a pure atmosphere. If respiration has ceased, it must be restored by artificial means.

When the pulse is weak, it becomes necessary to administer stimulants acting on the heart and stomach. Good results in such cases have been obtained by Dr. Morris with hypodermic injections of ether.

The first effect of fresh air on a victim of CO poisoning seems to be attended with a certain danger. On the occasion of a firedamp explosion at the Albion Colliery it was found that several of the miners suffering from CO poisoning first lost consciousness on being brought to bank. This unfavourable symptom has also been observed in other cases of pit accidents, and no satisfactory explanation has yet been afforded. Possibly the reduction of pressure on ascending to the pit mouth diminishes the flow of blood to the brain, and thus causes loss of consciousness.

In cases of CO poisoning among small animals, a considerable diminution in the generation of heat is observed; but this is perfectly natural, in view of the fact that the absorption of oxygen into the blood is retarded. Recovery in pure air is considerably accelerated by warming the animal under experiment. The application of artificial heat seems therefore indicated in such cases of poisoning, and it is advisable to apply hot-water bottles to the sufferer and wrap him in woollen blankets.

Exceedingly favourable results attended the exhibition of pure oxygen, by inhalation, in restoring consciousness to the victims of CO poisoning at the Micklefield Colliery explosion. This explosion took place on 30th April 1896, and resulted in a loss of 60 lives. The pit is not a gassy one, but is very dusty. In the opinion of the Committee of Inquiry, 46 of the victims were killed by the action of CO in the afterdamp. A number of the rescuers were made seriously ill from the same cause, and had to be sent up as quickly as possible, the CO being evidently to blame, since the lamps continued to burn regularly, and therefore the symptoms could not be attributed to a lack of oxygen in the pit air. A supply of condensed oxygen was readily available, and proved highly useful in restoring the sufferers to consciousness.

True, as the following example will show, one must not expect too

much from the employment of condensed oxygen. One of the Micklefield miners was discovered, still alive but senseless, among a number of the dead, 56 hours after the explosion. A little farther on, it may be remarked in passing, a pony was found in a healthy condition. Dr. Haldane was in the pit at the time this man was discovered, and immediately proceeded to administer oxygen. Breathing and pulse were both regular, but the members were cold. After wrapping up the victim as warmly as possible, he was caused to inhale pure oxygen for 20 minutes, the gas being supplied through a tube placed in the mouth, with the precaution that the nostrils were compressed at each breath. He was then sent up to bank in a litter as quickly as possible, laid in front of a good fire, and surrounded with warm-water bottles until the members attained a sufficient temperature. The blood of this patient was found to be saturated to the extent of 20 per cent. of CO after half an hour's sojourn above ground. The temperature was normal, and his condition seemed to have improved; nevertheless he remained unconscious and died the following day, the exposure to the poisonous gas having been too protracted to admit of recovery.

18. HYDROGEN (H) is also a colourless, inodorous, and tasteless gas, which burns in air with a somewhat reddish, faintly luminous, though extremely hot flame. Although not poisonous, the gas is incapable of supporting life. In the coal pit it is liberated in cases of fire, along with other unconsumed gases, from the distillation of the coal, on the explosion of blasting charges of inferior powder, and also in smaller amount in fire-damp explosions and coal-dust explosions. By reason of its affinity for oxygen, it increases the explosive and combustible character of inflammable gaseous mixtures to a very considerable extent, even though present only in minute quantities.

19. SULPHURETTED HYDROGEN (H_2S) is a colourless gas, with a disagreeable smell of rotten eggs and a sweetish taste. It burns with a bluish flame, sulphurous acid and water being formed. When inhaled it is exceedingly poisonous, more so indeed than carbon monoxide. Birds will die when placed in an atmosphere containing 0·07 per cent. (1 part in 1500) of this gas; dogs when the percentage reaches 0·125 per cent., or 1 part in 800. The presence of 0·1 per cent. is sufficient to produce unconsciousness in man within a short time, and finally lead to fatal results.

Sulphuretted hydrogen occurs in many natural mineral waters; it is also formed during the putrefaction of sulphurous organic matter and in the decomposition of metallic sulphides. In mines this gas frequently appears in small quantities associated with firedamp, and is also liberated

to a very troublesome extent in blasting,—especially in the case of damp charges, and black powder deficient in saltpetre.

20. Water Vapour.

Like the majority of gases, atmospheric air absorbs a larger or smaller proportion of water vapour—according to the temperature and pressure—in all degrees up to saturation point. Pit air is for the most part completely saturated with water vapour, or nearly so, since nearly everywhere underground water escapes from the rock and is vaporised. An unfavourable effect on human health is produced by an insufficiency as well as by an excess of moisture in the air. As the proportion of moisture present modifies the specific gravity of the air, the amount may be ascertained by a specific gravity instrument or hygrometer, the usual form being that invented by Daniel (Fig. 1).

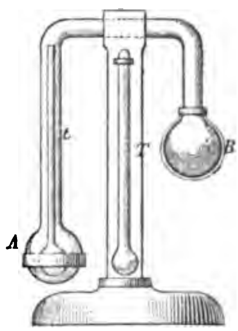

Fig. 1.—Daniel hygrometer.

Two hollow glass bulbs, A and B, are connected by a bent glass tube. The bulb A is fitted with an external annular covering of gold, on which the deposition of dew can be observed. This bulb is charged with ether, into which dips the bulb of an enclosed thermometer *t*. The second bulb B is surrounded with gauze. The interior of the apparatus is exhausted of air, and a second thermometer T, for recording the temperature of the surrounding air, is mounted on the stand of the hygrometer. On pouring a few drops of ether on the bulb B, the latter is rapidly cooled down by the evaporation of the ether, whereupon the ether in A is volatilised and passes over for condensation into B. This causes A to cool down, the result being a deposition of moisture (dew) from the surrounding air upon the gold ring A. The temperature at which this occurs is known as the dew-point, *i.e.* the air surrounding A is now so far cooled as to be saturated with the contained water vapour. The temperature of this dew-point is indicated by the interior thermometer; but, as this thermometer is necessarily somewhat cooler than the surrounding air, the temperature it records is lower than the truth. For this reason the observer waits until the dew disappears again from the gold ring, then takes a second reading, and sets down the mean Ti of the two. The temperature Ta of the outer thermometer T is also noted down. The degree of saturation E of the external air is equivalent to the tension f of water vapour at the dew temperature Ti, divided by

the tension F of water vapour at the outer temperature T*a*. Consequently $E = \frac{f}{F}$. The respective tension (f and F) of water vapour at the internal and exterior temperatures is found in Table (p. 37), when it is a question of determining the weight of a cubic metre of pit air.

TABLE OF AIR TEMPERATURES, WITH TENSION F OF THE CONTAINED WATER VAPOUR AT COMPLETE SATURATION. THE TENSION IS EXPRESSED IN MILLIMETRES OF MERCURY.

(*For Calculation in Metres divide by* 1000.)

Temperature.	Tension F of Water Vapour.	Differences.	Temperature.	Tension F of Water Vapour.	Differences.
°C.	mm. Hg.		°C.	mm. Hg.	
0	4·6	0·34	27	26·50	1·60
1	4·94	0·36	28	28·10	1·68
2	5·3	0·39	29	29·78	1·77
3	5·69	0·41	30	31·55	1·85
4	6·10	0·43	31	33·40	1·96
5	6·534	0·47	32	35·36	2·05
6	7·00	0·49	33	37·41	2·15
7	7·49	0·53	34	39·56	2·27
8	8·02	0·55	35	41·83	2·37
9	8·57	0·59	36	44·20	2·5
10	9·16	0·63	37	46·7	2·6
11	9·79	0·67	38	49·3	2·7
12	10·46	0·70	39	52·01	2·89
13	11·16	0·74	40	54·906	6·485
14	11·91	0·79	45	71·391	20·591
15	12·699	0·837	50	91·982	25·496
16	13·536	0·87	55	114·478	31·313
17	14·42	0·95	60	148·791	38·154
18	15·36	1·00	65	186·945	46·148
19	16·37	1·04	70	233·093	55·424
20	17·39	1·10	75	288·517	66·126
21	18·49	1·17	80	354·643	78·398
22	19·66	1·23	85	433·044	92·351
23	20·89	1·296	90	525·392	108·300
24	22·18	1·37	95	633·692	126·308
25	23·55	1·44	100	760·0	
26	24·99	1·51			

21. SULPHUROUS ACID, H_2SO_3, is at the ordinary temperature a colourless gas, of disagreeable pungent smell and poisonous action; it is formed in small quantities in chokedamp, and in the afterdamp succeeding firedamp explosions. According to Lehmann, the presence of 0·001 per cent. of this gas in the air is sufficient to produce slight irritation of the mucous membrane of the respiratory organs; and with 0·003 per cent. the irritation becomes clearly apparent. Ogata found that, in the case of rabbits and other small animals, 0·04 per cent. of sulphurous acid was sufficient to produce pectoral congestion, as well as inflammation of the eyes and air passages; 0·1 per cent. produces fatal results in a few seconds.

This gas causes the decomposition of the red blood corpuscles, and thus renders the two absorption lines exhibited by dissolved blood less clearly visible than is otherwise the case.

METHANE, pit gas, marsh gas (firedamp), CH_4, has the specific gravity 0·558; 1 cubic metre weighs 0·7218 kilogramme.

22. Occurrence of Firedamp in Nature.

In certain collieries the mining operations pursued in winning the coal cause the liberation of a larger or smaller volume of a light hydrocarbon gas, methane, which when mixed with atmospheric air is termed firedamp by the miners, on account of its inflammable character and its property of exploding with violence under certain circumstances. This firedamp plays an important part in the working of such gassy seams, on account of the dangers to which it gives rise, the difficulties it produces in coal getting, and the arrangements and precautions that have to be devised on this score. Nevertheless, despite all precautions, firedamp explosions still occur, and are attended with very injurious consequences to both the health and the life of the miner. Firedamp is also encountered in salt mines, in variegated sandstones and clays where saline deposits are found, and also wherever petroleum is discovered; and it often escapes in large quantities from the ground, either associated with this oil or alone.

Methane is also known as marsh gas, because it is formed in abundance from putrefying vegetable matter in the mud of peat mosses, and escapes in the form of large bubbles on this mud being stirred. Since coal seams were undoubtedly formed by the decomposition of vegetable matter, under the conjoint action of moisture and heat generated by pressure, in the absence of air, it is evident that hydrocarbons must also have been produced at the same time. These have either been dissipated, owing to the absence of an hermetical cover rock of sufficient thickness and closeness of texture, or else have remained behind, wholly or in part, on the deposition of impermeable strata above the coal seams.

Since certain coal seams are even now undergoing a slow process of decomposition, or dry distillation, and—owing to the inequality prevailing in respect to the extent with which decomposition has proceeded—contain unequal percentages of volatile constituents, it is probable that, under certain circumstances, the formation of methane is still going on.

Though firedamp is usually only met with in bituminous coal seams, yet there are some seams of this kind that are free from gas; conversely, it may happen, though rarely, that gas is met with in anthracitic coal

seams, *e.g.* those at Charleroi. Irregularity also prevails with regard to the appearance of inflammable gases in different parts of one and the same seam or group of seams. When the adjacent rock is porous, this also may become impregnated with firedamp. The most gas is generally found in disturbances and fissures, containing cavities or disintegrated rock affording space for the accumulation of the gas. Moreover, horizontal portions of a seam—as is, for instance, the case in the Hibernia pit at Gelsenkirchen—usually contain more gas than the inclined portions, apparently because the gas has greater opportunities for escaping from the inclined seams, in the direction of stratification, than it has for passing transversely through the strata in the other case. On account of the greater pressure, the accumulation and density of the gas increase with the depth, and consequently the danger of firedamp explosions increases in a corresponding manner. At the same time, since the rock temperature increases with the depth, a more extensive liberation of gas occurs.

As a general rule, the pit gas is intimately combined with the coal, and occupies all the cavities therein. In such event, it escapes from the exposed wall of coal in proportion as the work of coal getting proceeds and the seams are traversed by headings, the escape being frequently accompanied by a peculiar noise resembling the sound produced by rubbing crab shells together, or like the patter of fine rain on foliage. This noise is observed where the gas is being liberated in quantity from damp coal and under pressure. It may be remarked, in passing, that a similar noise is made by carbon dioxide in escaping under analogous conditions from the coal; this has been noticed at the Haenichen Colliery near Dresden.

23. Blowers. — Firedamp sometimes occurs in so-called blowers, which greatly resemble water springs, issuing from fissures in the rock. These blowers often continue to discharge gas for weeks and months in succession, in which event they must communicate with extensive reservoirs in the adjacent rock, partly filled with dust or loose rock, or with faults, some of which latter may traverse several seams.

24. Sudden Outbursts of Gas (Dégagements instantanés).—In contrast to the above-mentioned occurrence of methane, wherein the gas uniformly permeates the entire mass of the coal, or issues from cracks and fissures in the rock, another method of occurrence is known, peculiar to Belgian coal basins, the gas being found in large volumes and under a high pressure, accompanied by a certain kind of very porous coal dust (houille daloide), imprisoned in large underground chambers. When a reservoir of this kind is accidentally tapped in driving a heading, an irruption of large volumes of gas and coal dust occurs with great

suddenness, filling up the workings immediately and causing enormous devastation.

These occurrences seem to have a very intimate connection with local geognostic conditions, and are caused by the extensive dynamic disturbances in the Belgian coal measures, as may be gathered from the plans and profiles of such pits. At some time or other the Belgian coal measures have been subjected to an extremely heavy horizontal pressure, in consequence of the shrinkage of the earth and the subsidence of its solid crust. This has caused extensive lateral thrust, tilting, folding, buckling, and overthrow, the result being that some of the formations, instead of being thrust under, above, or side by side with one another, have been telescoped one into the other with enormous force. The natural consequence of this is that certain parts of the rock, and especially the less solid coal seams, must have been ground down and disintegrated in places, and this rock, interspersed with cavities, has then absorbed gas liberated by the coal, the gas itself being greatly compressed by the heavy rock pressure.

It is also quite natural that such disintegrated masses of rock should only be encountered at great depths, since rocks near the surface would, on being exposed to such unusual horizontal pressure, be more easily deflected upwards and so escape disintegration.

The extensive and sudden irruptions of gas and coal dust in the pits at Gard, Midi de Dour, and Agrappe (Belgium) are well known. At the last-named colliery about 500,000 cubic metres of gas and a great mass of coal dust broke out into a heading at a depth of 610 metres (2000 feet), blocking up all the workings and the shafts, and taking fire at the pit mouth, all the head gear, buildings, etc. being thereby entirely destroyed. When the liberation of gas subsided a little, violent explosions occurred in the workings, and the shaft openings were rendered quite inaccessible. This accident involved the sacrifice of one hundred and one lives, in addition to eleven men injured.

Where such sudden and enormous outbreaks are caused by the conditions of deposition, it is almost impossible to guard against their occurrence; whilst otherwise firedamp explosions in mines can best be hindered by preventing any accumulation of the gas, and by removing the liberated gas, where it occurs continuously from the coal, rock, or blowers, by the aid of a powerful ventilating current, and finally diluting it to such an extent that ignition or explosion is no longer possible.

To prevent one or all of the seams in a section of the workings from getting overwhelmed with firedamp when the same is uniformly distributed, it is furthermore advisable to subdivide the section into

smaller working fields as quickly as possible, by driving the drainage galleries, middle galleries, and air ways, and then the inclines, as far as the boundary, or to the natural limit of the mine (fault), and in this manner tap the seams to some extent before commencing the work of coal getting, which will expose every day a large surface of gas-exhaling coal.

Of course it will be necessary in this preparatory work to have a good system of mechanical ventilation already installed, of the kind that will be referred to later on; the same is also indispensable for the subsequent coal getting.

Physical and Chemical Properties of Firedamp.

25. In many cases firedamp does not exclusively consist of pure methane, and it is frequently a mixture of olefiant gas (C_2H_4), nitrogen, oxygen, carbon dioxide, hydrogen, and occasionally small quantities of sulphuretted hydrogen. In Belgian pits the admixture reaches as high a figure as 30 per cent., but generally is only about 10 to 15 per cent. According to the tests made at the Hibernia pit (Westphalia) in 1894 and 1895, the firedamp at this colliery contained—methane, 95 to 99·5 per cent.; CO_2, 0·44 to 1·6 per cent.; and nitrogen, 0 to 4·5 per cent. By reason of the presence of other gases, the specific gravity of firedamp is higher than that of pure methane, and reaches about 0·7.

26. Methane is colourless, inodorous, and tasteless. Some miners, however, profess themselves able to see firedamp, the appearance being said to resemble that of a spider's web. According to Dumas, the explanation of this assumption is as follows:—By reason of its lower density, the methane accumulates near the roof of the headings, and, as the rays of light in passing through air strata of different density are refracted differently, the phenomenon becomes visible. Among English miners this appearance is termed silver gas.

A person accustomed to sojourning in firedamp experiences a peculiar sensation on entering an atmosphere highly charged with this gas. Though the latter should be tasteless and inodorous, it is credited with possessing a flavour similar to that of apples, and a curious smell that is difficult to describe but is very well known to the miner. When taken into the lungs, firedamp is not poisonous; nevertheless, like nitrogen and hydrogen, it is incapable of replacing oxygen as a supporter of life, and therefore produces suffocation when in the pure state or present to the extent of 50 per cent. in the inhaled air.

According to Guibal, even 33 per cent. of firedamp in air will produce

suffocation, whilst 5 per cent. will extinguish the flame of a safety lamp. Hence, apart from the risk of ignition, care is necessary in entering an atmosphere laden with firedamp—for example, in ascending a pit incline for the purpose of rectifying the ventilation at the upper end, the danger being intensified by the fact that the percentage of gas increases very rapidly in the higher levels, so that one might suddenly find himself in an atmosphere containing too little oxygen to maintain life. With a view to obviating this risk, the advance should be gradual, and the explorer should be followed by one or two men a short distance in the rear.

It is also necessary, in traversing fiery mines, to hold the lamp low down, the dangerous gas, as has been said, accumulating at the top and diffusing but imperfectly. On the other hand, when it is desired to test the condition of the atmosphere by means of the lamp flame, the lamp should be raised and the test applied near the roof.

Even where galleries and working places are traversed by a ventilating current, accumulations of firedamp will often remain obstinately in cavities in the roof, and resist diffusion. However, once the gas has become mixed with the air, it will not separate again.

Inflammability of Firedamp.

27. Firedamp is ignited by a flame, since the two constituent elements C and H are able to combine with O, a lambent bluish flame being generally produced. Water and carbon dioxide are the products of combustion. When ignited in a current of pure air, pure methane burns with a white flame, the reaction proceeding in accordance with the equation—

$$CH_4 + 2O_2 = 2(H_2O) + CO_2.$$

Owing to the fact that the water vapour produced by the reaction is almost instantaneously cooled and condensed, two shocks, the shock proper and the counter-shock, are produced in quick succession when an explosion of firedamp occurs. The former results from the sudden expansion of the hot gases at a pressure of 4 to 6 atmospheres; whilst the weaker counter-shock is caused by the inrush of air to occupy the vacuum formed by the condensation of the resulting water vapour. The ignition temperature of firedamp is 650° C. according to Demanet, or 780° C. according to Koehler. The only way to produce ignition is by contact with a flame or an electric spark. As a rule, no ignition is produced by glowing iron, glowing tinder, or by the spark formed by the impact of a steel tool on a hard object (rock, etc.); though instances have been

reported where ignition of firedamp has been alleged to have ensued from the sparks produced by a drill working in hard sandstone. In a Galician petroleum shaft, where a hewer was working without a light on account of the shallow depth of the pit, an explosion was caused by the stroke of a pick. The circumstance that glowing iron does not usually cause the ignition of firedamp is explained by the so-called retardation of ignition. The inflammable gaseous mixture requires a certain time to attain the ignition temperature, but as the particles of gas in contact with the hot metal become lighter than the rest as they are warmed, and therefore ascend, they cannot become heated to the requisite point for ignition to ensue. The case is different when their ascent is retarded by any obstacle, such as an inverted bucket, etc., above the glowing metal; and in such event an ignition of the inflammable mixture might easily occur.

The ignition of firedamp during shot firing will be dealt with later in the chapter on Coal Dust.

The inflammability and explosibility of firedamp vary in accordance with the proportions of the mixture with air. In the event of the firedamp consisting of pure methane, and the air containing 23·1 parts by weight of oxygen and 76·9 parts of nitrogen, the most violent explosion would occur in the case of a mixture containing $1 \div 7{\cdot}4 = 13{\cdot}5$ per cent. by volume of methane. Owing, however, to the fact, as already stated, that pit gas also contains other gases, the maximum explosibility is exhibited when the proportion of firedamp is about one-eighth to one-ninth the entire mixture, *i.e.* 12·5 to 11·1 per cent. When the proportion of gas is as low as one-thirtieth to one-fifteenth (3·33 to 6·66 per cent.) of the total volume, the ignition of the mixture is confined to such portions as are immediately in contact with the igniting flame. The resulting combustion does not spread over the whole mass, but the flame becomes elongated and broader in proportion as the gas content increases, and is surrounded by a lambent aureole, or flame cap, which diminishes in proportion as the percentage of the mixture approximates to one-thirtieth, at which point it disappears. When the gas content rises to one-fourteenth (7·1 per cent.), ignition extends throughout the entire volume of the mixture, and a slight explosion occurs. The more the percentage of gas increases the more decided is the ignition, and consequently the more violent the explosion, the maximum being attained at one-eighth. Beyond this point the violence of the explosion again diminishes, the amount of oxygen present being then more and more insufficient to permit complete combustion of the carbon and hydrogen to CO_2 and H_2O. The detonations therefore gradually decrease in intensity, and cease entirely when the proportion of gas has reached one-third of the total

volume of the mixture, at which point simple ignition occurs. The final limit of inflammability is reached at 50 per cent., beyond which point the mixture will not burn at all, and in fact simply extinguishes an introduced flame. The above particulars have been collected into the table now given.

Ratio of CH_4 to Air (by Volume).	Reaction.
Below $\frac{1}{30}$	None.
Between $\frac{1}{30}$ and $\frac{1}{15}$	The aureole round the flame gradually increases.
At $\frac{1}{15}$	The ignition of the mixture is communicated to the entire volume.
At $\frac{1}{8}$	Maximum of explosibility.
Between $\frac{1}{8}$ and $\frac{1}{5}$	The explosions diminish in intensity.
Between $\frac{1}{5}$ and $\frac{1}{2}$	Simple ignition.
Above $\frac{1}{2}$	The mixture ceases to ignite, and extinguishes any flame introduced therein.

An addition of one-seventh = 14·5 per cent. of carbon dioxide to the most explosive mixture of air and firedamp entirely deprives it of this property. Of course no one could live in such a mixture, nor would any light burn therein.

Pressure under which Firedamp is imprisoned in Coal.

28. The hissing of escaping firedamp, already alluded to, indicates that the gas is imprisoned under pressure in the coal. This is perfectly natural, the rock pressure implying a corresponding pressure in the contained gas when the latter has no avenue of escape.

The gas pressure can be measured by means of a pressure gauge inserted air-tight into a borehole drilled for a depth of several metres into the coal. An approximate idea of this pressure can also be obtained by immersing in water a piece of coal, freshly detached from the working face, collecting the evolved gas, and comparing the relative volume of this gas and the lump of coal.

This gas pressure, which naturally increases towards the interior of the mass of the coal, is often very considerable. According to Behrends, a pressure of 14·6 atmospheres was observed at the bottom of a borehole, 4 metres in depth, in a newly opened section of the No. 13 seam at the Hibernia Colliery, Gelsenkirchen (Westphalia). In very deep Belgian pits, pressures of 20 to 23 atmospheres have been recorded, and as high as 42·5 atmospheres in a borehole in unworked coal.[1] It may therefore

[1] The theory that firedamp may be present in a liquid or solid condition in coal seams, by reason of high pressures, is untenable, since the critical point of this gas resides at $-81·8°$ C. and 54·9 atmospheres pressure, whereas such a low earth temperature is impossible.

be accepted as a rule that the greater the depth of a seam below the surface, and the more effectually it is shut off by impenetrable cover rock, the higher will be the pressure of the imprisoned gas, and consequently the more violent the outrush of gas when the seam is tapped. On the other hand, the longer the seam is worked and the greater the number of galleries and other openings made therein, the more will the initial pressure and outflow diminish in course of time, until finally the latter ceases altogether or diminishes to an imperceptible quantity. From this it follows that a larger amount of gas will be met with in opening out a new section than when the same is being worked and has long been traversed by headings. There is thus evidently a certain analogy between the occurrence of firedamp and pit water, inasmuch as in both cases the initial outflow is the greatest, diminishing in a short time as drying progresses.

Some relation must undoubtedly exist between the pressure under which gas is imprisoned in the coal and the volume escaping therefrom, this being a natural law. Nevertheless, there is no practical advantage to be derived from expressing the relation between gas pressure and volume liberated by mathematical formulæ, such, for instance, as the formula for the equivalent orifice, according to which $Q = \mu a \sqrt{2gh}$, wherein Q indicates the volume of the outflow in cubic metres per second, μ the coefficient of contraction, a the equivalent orifice in square metres, $g = 9{\cdot}81$, and h the pressure in millimetres of the water gauge. (This formula will be referred to later on.)

No serviceable value or regularity can be laid down for the dimension a of the effluent orifice from the solid coal; and besides, these orifices are numerous and not confined to a single one. Moreover, since the pressure h has no constant value in the present case capable of being accurately determined beforehand for even a small portion of the area, and since this pressure diminishes in an uncontrollable degree as the liberation of gas proceeds, it is evident that a mathematical treatment of the question will lead to no practically useful result. If no further production of gas occurs in the coal, under the conditions of temperature prevailing in the rock, then the escape of gas must cease at some time or other after the section of the field has been tapped. Of course the total amount of gas escaping from the pit will not suffer diminution (and may even increase), so long as fresh gassy portions of the field continue to be opened up and placed in communication with the existing workings; and this is a contingency that must be borne in mind when planning out the working and ventilation of a mine. The outflow of gas can be to some extent kept under control, inasmuch as it is possible to reduce the volume of

gas that has to be daily or hourly removed by the ventilating current, by limiting the output of coal, and more especially by regulating the preliminary work of opening up new sections of the pit.

29. Since, under ordinary conditions, the gas intimately permeates the coal and fills its pores at a higher or lower pressure, the gas also influences the coherence and firmness of the seam, and, under certain circumstances, may make the coal friable and brittle. For this reason, fiery bituminous coal seams frequently yield nothing but small coal; and occasionally this factor becomes so prominent as to make coal getting dangerous, especially in sloping seams. This evil can be counteracted by tapping the seam with boreholes before commencing to win coal from the face: in this way the coal is rendered more solid and resistant. More especially has this contingency to be taken into consideration when two gassy seams are situated in close juxtaposition. In such event the coal could undoubtedly be more easily won by working both seams simultaneously, but only small coal would be obtained; whereas, by working one seam before the other, an opportunity is afforded for the gas in the second one to escape, and the coal won from this will then be more solid and furnish a larger proportion of lumps.

Influence of Atmospheric Pressure on the Liberation of Firedamp.

30. The escape of firedamp is influenced by another important factor, namely, the pressure of the atmosphere. It frequently happens that a condition of high or low atmospheric pressure prevails for many days in succession; but, on the other hand—and especially at certain times of the year—considerable changes in pressure may occur within twenty-four hours, or even a shorter time. It is assumed that such fluctuations of pressure have a by no means inconsiderable influence on the outflow of certain springs; so much the more should they have an effect on the outflow of firedamp, a substance of such tenuity and elasticity that its volume is affected by the slightest alteration of pressure. As the barometer falls, so the firedamp escapes in larger amount, the converse occurring when the glass rises; and an increase is noticeable in stormy weather. This will be easily understood when it is remembered how greatly gusts of wind affect the escape of smoke from the chimney stacks of factories, dwellings, etc. On the other hand, it is freely admitted, and regarded as a happy circumstance, that the ventilation of a large mine, when carefully planned, supervised, and carried out by the aid of powerful fans—but in such event only—is not

so readily subject to disturbance from this cause; but, as we shall see later on, this influence of so-called natural ventilation still makes itself felt even in the case of artificial ventilating currents, and consequently any change in the atmospheric temperature or pressure will have some effect on the liberation of firedamp.

If we regard the gas pressure existing in the coal of a fiery pit as representing one limb of two vertical tubes, filled with liquid and connected at their lower extremities, the second limb being formed by the atmosphere, it will be evident that any alteration of pressure, or any movement in the one limb, cannot remain without influence on the condition of the other limb.

Also subject to the influence of atmospheric pressure are any accumulations of gas in the cavities of the worked-out portions of the pit (goaf) and in the interstices of the packing; expanding when the pressure diminishes, and escaping into such portions of the workings as are traversed by the ventilating current, and thus raising the percentage of gas therein beyond its normal level.

The influence of atmospheric fluctuations on the liberation of firedamp from coal has been set beyond doubt by the observations made in the collieries of the Archduke Albrecht at Karwin (Moravia), the aforesaid Hibernia pit in Westphalia, and at other collieries in different countries.

In a communication dealing with the firedamp question, Behrends reviews the observations made by himself and W. Koehler in this connection, as follows:—

(1) Increasing atmospheric pressure retards the escape of firedamp, whilst diminishing pressure accelerates it.

(2) The greater the increase in atmospheric pressure per unit time, so much the more is the liberation of gas diminished; the more the pressure falls per unit time, the larger is the escape of the gas.

(3) If the barometric pressure, having attained a certain height—the result of which has been to diminish the escape of firedamp—remains at that level for some time or permanently, the percentage of gas gradually increases again, though without attaining the original figure, so long as the increased pressure continues. The diminution in the outflow, induced by a permanent increase in the atmospheric pressure, is smaller when the gas pressure in the coal is high, and greater when the gas pressure is low. Conversely, when the atmospheric pressure falls—which condition is accompanied by an increase in the escape of gas—and then remains at this point, either for some time or permanently, the percentage of gas gradually decreases again, though it does not recede

as low as the original level, so long as the pressure remains constant; the increased outflow of gas, due to the permanent fall in the pressure, is smaller when the gas pressure in the coal is high, and greater when the gas pressure is low.

(4) Should a sudden rise of atmospheric pressure be succeeded by a more gradual increase, a slow acceleration of the gas outflow ensues; on the other hand, when a rapid fall in the barometer is followed by a more gradual one, the retardation of the gas outflow proceeds slowly. In no case, however, do the maxima or minima of the barometric curves correspond to maximum or minimum rates of outflow of the gas.

In England special attention is paid to barometric observations in the case of fiery mines, the state of the glass being examined several times a day by the officials, and the readings entered in the journal. This procedure has its justification in the circumstance that, in consequence of the stratigraphical condition of the seams and the methods of working pursued, large empty chambers are frequently left in the goaf, which spaces fill up with firedamp. Falls of roof or sudden barometric depressions may force this gas into the workings, and give rise to explosions. There is no doubt that great explosions of firedamp often coincide with falls in the atmospheric pressure, and that consequently attention must be paid to the latter. Again, accessions of temperature and fluctuations in the percentage of moisture in the air, especially in the warmer seasons of the year, are not without influence on the escape of firedamp.

The following short table gives a review of the firedamp explosions occurring in English collieries from 1868 to 1872, and shows that one-half of these coincided with fluctuations of atmospheric pressure:—

Year.	No. of Explosions.	Proportion attributable to		Proportions due to other Causes.
		Falls of the Barometer.	Rises of the Thermometer.	
		Per cent.	Per cent.	Per cent.
1868 . . .	154	47	27	26
1869 . . .	200	48	17	35
1870 . . .	196	50	24	26
1871 . . .	207	55	19	26
1872 . . .	233	58	17	25

It is thus evident that half these explosions were coincident with falls of the barometer, one-quarter with accessions of atmospheric temperature, and one-quarter with undetermined causes.

Since, as we have seen, fluctuations of atmospheric pressure have certainly an influence on the liberation of firedamp, meteorological stations should be provided at all fiery pits, and daily observations of the barometer and thermometer should be made and entered in the journal. On days when a heavy fall in the barometer is noticed, special care should be bestowed on the possibility of accumulations of firedamp, and great precaution observed in shot firing.

CHAPTER II.

PREVENTING THE DANGERS RESULTING FROM CONTAMINATION OF PIT AIR.

DETERMINING THE PERCENTAGE OF METHANE IN PIT AIR—TESTING FIREDAMP—FIREDAMP INDICATORS.

31. The percentage of methane in pit air can be accurately determined by chemical analysis. For this purpose, samples of air must be taken at the places where a knowledge of the composition is desirable, and these samples submitted to examination in the laboratory. In this connection reference may be made to Winkler's Technical Analysis of Gases, and to Dr. Schondorf's paper on the Laboratory Apparatus of the Prussian Firedamp Commission, in *Zeitschrift für das Berg-, Hütten-, und Salinenwesen*, 1887.

For the estimation of carbon dioxide, carbon monoxide, and oxygen the Schwackhoefer apparatus may be used; and all gases, methane included, may be determined by the Orsat apparatus. The Bunte burette can also be employed for this purpose; whilst the Coquillon "Grisoumetre" (firedamp tester) is intended for estimating the percentage of firedamp exclusively.

By means of such gas analyses the composition of the air in the upcast ventilating shaft can be ascertained, and, when the volume of the effluent air has been determined by measurement (an operation which will be described later on), the total amount of firedamp discharged from the pit will be revealed. The same can also be done in the case of split air currents, and will permit of measures being taken to diminish the percentage of gas in the main current or in a branch of same. This estimation of methane by analysis is indispensable in all fiery pits; though such analysis will not preclude the risk and possibility of firedamp explosions in portions of the pit where inflammable gaseous mixtures can be formed.

For this reason it is desirable, and even necessary, that one should be able to ascertain, *in situ*, the percentage of firedamp in the pit air wherever firedamp makes its appearance, even in minute quantities.

It has already been stated that methane is considerably lighter than ordinary air, and that consequently it preferably accumulates against the roof or in cavities therein, and will obstinately remain there unless directly encountered and driven away by the ventilating current. Hence we may always expect to find a larger percentage of firedamp near the roof than elsewhere. It was also mentioned that this gas in burning exhibits a flame by which its presence is revealed; and, in fact, the flame of the miner's lamp is the only known means whereby the occurrence of this gas in any place can be detected. Of course, when a flame is used for ascertaining the presence of firedamp, the experiment must not be made with a naked light, but with the flame of the safety lamp. And, as every miner in the pit should be in a position to detect the presence of firedamp, up to a certain extent, in his working place by means of his lamp, it follows that safety lamps alone should be allowed in any fiery pit—as is indeed made obligatory by legislative or other administrative enactments.

The first Davy safety lamp (Figs. 2 and 3, Plate I.) afforded, as is well known, but little protection and security against the penetration of the lamp flame through the gauze, or against the ignition of inflammable gaseous mixtures, and therefore urgently needed improving. Nevertheless, on account of its simplicity and convenience, it still remained in use for testing the presence of firedamp, even after the introduction of improved lamps. According to Davy's own observations, the flame in his lamp underwent a decided elongation in presence of 3·33 per cent. of gas. According to Koehler, the shortened flame of the Davy lamp, burning rape oil, in presence of—

2	per cent. of gas,	is elongated by	an aureole of	7	mm.
$2\frac{1}{2}$	,,	,,	,,	10	,,
3	,,	,,	,,	20	,,
$3\frac{1}{2}$	,,	,,	,,	35	,,
4	,,	,,	,,	60	,,

When the percentage of gas reaches $4\frac{1}{2}$ per cent. the apex of the flame touches the top of the gauze cylinder.

According to Lamprecht, it is possible with a little skill to detect 2 per cent. of gas by means of the Mueseler oil safety lamp, though the lowest limit of definite indication is afforded by 3 per cent.

In making the test the lamp should be raised very slowly from the gallery floor to the roof, and then lowered again in the same manner.

Early in the 'eighties a proposal was made by Pieler, of Ruda (Upper Silesia), to feed the Davy lamp, for testing purposes, with pure spirit, absorbed by cotton-wool, instead of with rape oil. The spirit flame,

though intensely hot, has but little illuminating power, but, in presence of an inflammable gas in the atmosphere, elongates and surrounds itself with a bluish aureole (flame cap); consequently, by suitably shortening the wick, the presence of $\frac{1}{4}$ to $\frac{1}{2}$ per cent. of methane can be detected by this means. When the gas content attains $1\frac{1}{2}$ per cent. the flame reaches to the top of the gauze cylinder, so that no larger percentage can be detected. In using a spirit lamp for testing purposes it is necessary to also have an ordinary safety lamp at hand to give light, since the illuminating power of the former is practically nil. Furthermore, the lamp is a source of danger when the gas content reaches $2\frac{1}{2}$ to 3 per cent., and therefore some means must be employed for instantly extinguishing the flame when necessary.

Superiority in this respect is exhibited by the Clowes lamp for testing firedamp (Fig. 4), this being fed with pure hydrogen. It was based on the construction of the Gray oil safety lamp, and will reveal, by the flame cap, from 0·2 to 6 per cent. of methane, and can also be used for ordinary lighting purposes.

Fig. 5 illustrates the Chesneau test lamp, which is similar to the Pieler-Davy lamp, and is fed with methylated spirit, containing a little ethylene chloride and copper nitrate, this admixture giving the flame a greenish tinge, and therefore rendering it more visible.

The Friemann and Wolf (Zwickau) spirit-fed testing lamps, illustrated in Figs. 2 and 3, are graduated on the outside to indicate the length attained by the flame in presence of different percentages of methane in the air. Absolute alcohol is the fuel used. Before applying the test, it is advisable to regulate the flame in pure air in such a manner that the tip of the flame cone is flush with the upper rim of the small sheet-metal chimney.

On account of the great advantages exhibited by benzine safety lamps in comparison with those fed with rape oil, they have rightly almost entirely replaced the latter for pit use. These advantages also comprise superior capacity for indicating the presence of firedamp mixtures.

According to the makers' catalogue, the benzine lamp, with inside lighter and bottom draught, shown in Figs. 6 and 6*a*, is capable, with a little practice on the part of the user, of indicating as little as $\frac{3}{4}$ per cent. of methane, and $1\frac{1}{4}$ per cent. with perfect certainty.

Figs. 7 and 8 illustrate the appearance of the flame given by the lamp Fig. 6, the former figure showing the normal flame, and Fig. 6*a* the appearance of the flame when shortened by turning down the wick.

Readily Inflammable Explosive Coal Dust.

32. A second source of the origin and liberation of inflammable gases in coal mines is formed by a certain kind of fine coal dust—inevitably produced in coal winning, and distributed throughout the workings—which comes into play so soon as, from any cause, it is acted upon and gasified by a high temperature.[1]

Certain sintering (clod) coals and non-caking coals in many districts, and especially when present in thick seams, have long been known to possess the dangerous property of occluding and condensing oxygen, and then gradually entering into combination therewith to form carbon dioxide, the heat thus generated producing spontaneous ignition and pit fires, frequently attended with disastrous consequences.

The dusty state of these coals greatly facilitates the absorption of oxygen, and spontaneous heating. Moreover, it has now been indubitably demonstrated that the almost exclusive cause of serious explosions of coal dust in well-ventilated coal mines is the coal dust partly floating about in the pit air and partly deposited on the walls, floor, and timbering of the galleries, which dust may also have been the initial cause of the ignition. In the majority of instances this ignition is brought about by shot firing. It has been experimentally demonstrated that the dust of certain kinds of true coal is not only capable of producing explosion, even in the absence of firedamp, but inspection of the underground workings after an explosion has clearly shown that the explosion flame almost exclusively traverses the drainage galleries and main haulage and air ways, where also most of the victims of afterdamp are found, and that these galleries, though in general containing very little firedamp, exhibit quantities of coal dust, which is found, after an explosion, on the bodies of the victims, the timberings, and the floors, in the form of a degasified, coky incrustation. Apparently these particles of dust have been deprived, by dry distillation, of the bulk of their volatile constituents, which have then become ignited and fed the flame of the explosion, leaving the coky residue behind as a deposit.

As we know, the various kinds of coal contain very unequal percentages of volatile matters; and the volatilisation of these constituents also seems to be effected at different temperatures. This circumstance is the chief cause of the susceptibility of certain classes of coal dust to explosion. It may also be assumed that the physical condition of the

[1] Those acquainted with even the rudiments of chemistry will be aware that it is not the solid substance, in any case, that ignites direct and burns with a flame, but the gas—in the case of coal dust, combustible hydrocarbon—driven out from the solid body by any source of heat whatsoever.

coal—hardness, solidity, porosity, and friability—is not without influence on this susceptibility, or tendency to liberate methane when heated. At any rate, it is certain that the gas driven out of the coal dust by heat is what burns in the event of an explosion, and not the coal dust itself.

The gas first disengaged in considerable amount when coal dust is heated is undoubtedly methane, since, as we know, this gas is the first to pass over in any quantity in the production of coal gas by distillation. Methane is therefore revealed as the cause of firedamp explosions, no matter whether it is liberated from the coal at ordinary temperature or driven out by higher temperatures from the coal dust floating in the air of the pit or deposited anywhere therein. It is urgently desirable that this susceptibility of certain kinds of coal dust should be made the subject of a more thorough chemical investigation, and that it should be determined at what temperatures the liberation of methane from coal dust begins and reaches a maximum. It should also be borne in mind that the afterdamp following coal dust explosions (to retain this term for the sake of brevity, though admitting methane as the real cause of same) must invariably contain considerable quantities of carbon monoxide, since this afterdamp has proved itself so highly poisonous. Now, Dr. Brookmann of Bochum has shown that the product of the imperfect combustion of methane is ethylene (olefiant gas), and not carbon monoxide. Consequently the coal dust is the sole cause of the formation of CO, and of the poisonous and dangerous character of the afterdamp.

Experience has proved the great danger attending the presence of certain kinds of coal dust in mines; and it has furthermore been demonstrated that neither the provision of a powerful ventilating current, nor the division of extensive workings into smaller areas of ventilation, affords the least protection against the occurrence of explosions of firedamp and coal dust; but that, on the contrary, the dust is carried in larger quantities and to a farther distance from the centre of production the stronger the ventilating current traversing the mine. It thus became evident that the prevention of such catastrophes in future entailed the adoption of one of two courses,—either suppressing the formation and distribution of fine coal dust altogether, or, should this prove impossible, the employment of means to render the dust innocuous.

Method of rendering Coal Dust Innocuous.

33. The only means found capable of counteracting the excessive production of coal dust in the pit, and of rendering any existing dust

innocuous, is by thoroughly moistening and wetting the face to be next worked, and the coal won therefrom (this being the chief source of the dust), as well as to thoroughly saturate any dust that may have been formed despite the earlier precautions adopted. The various galleries, headings, etc. must be kept constantly wet for a distance of at least 30 feet from the working face, and all inclines in work must be wetted throughout their entire length. The same precaution must be adopted in the main haulage ways and drainage galleries, whilst, according to the experience gained in the Saarbruecken district, galleries connecting adjacent divided-current air ways are sufficiently protected by sprinkling in belts at intervals in their length.

Conveying the Water for Sprinkling the Coal and Coal Dust.

34. As a general thing, it may be taken for granted that every coal pit contains, in daily influx of pit water that has to be raised through the shafts, a sufficient quantity—at the rate of about 3000 to 3300 gallons per 100 tons of coal raised per diem—of water for the work of sprinkling. Should, in exceptional cases, the pit be free from water, or the influx be insufficient, then water must be led into the mine from the surface. In order to prevent clogging of the upcast pipes, the pit water is clarified before arriving at the pumps, by allowing it to pass through several broad settling basins, and finally through a sieve; and the water for sprinkling is delivered from the pumps—or special down-pipes, when these are required—into the different working levels, by means of pipes provided for that purpose.

As a working pressure in the delivery pipes, 5 to 10 atmospheres will be more than sufficient; and higher pressures will be required only in cases where the sprinkling mains have also to convey water for the transmission of power, and for driving underground machinery—a condition probably obtaining in the majority of mines. It must, however, be borne in mind that, in order to stand heavy pressure, the pipes will then have to be of more than the usual thickness—a circumstance that considerably increases the cost of installation.

The diameter of the pipes should be so chosen that the rate of flow will not much exceed 40 inches, even in the event of the network of pipes having to be subsequently extended in consequence of the working area of the pit being enlarged. As a rule, a diameter of 3½ to 4½ inches

COST OF PIPES PER 1 METRE RUN IN THE SAARBRUECKEN DISTRICT.

Wrought-iron pipes, to stand 10 atmos. pressure.			Wrought-iron boiler tubes, 50 atmos. pressure.			Loose flange wrought-iron tubes, asphalt-coated; to stand 10 atmos. pressure.			Mannesmann steel tubes.			Tubes coated with oil varnish.			Patent seamless steel tubes for 10 atmos. pressure.			Wrought-iron tubes from Berlin.			Welded wrought-iron tubes, coated with asphaltum.		
1			2			3			4			5			6			7			8		
Diameter.		Price.	Diameter.		Price.	Diameter		Price.	Diameter.		Price.	Diameter.		Price.	Diameter.		Price.	Diameter		Price.	Diameter.		Price.
Inside.	Outside.		Inside.	Outside.		Inside.	Outside.		Inside.	Outside.		Inside.	Outside.		Inside.	Outside.		Inside.	Outside.		Inside.	Outside.	
mm.	mm.	Sh.	mm.	mm.	Sh.	mm.	mm.	Sh.	mm.	mm.	Sh.	mm.	mm.	Sh.	mm.	mm.	Sh.	mm.	mm.	Sh.	mm.	mm.	Sh.
20	27	0·51	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	20	27	0·99	...	...	...
26	32·5	0·65	...	...	...	26	33	1·33	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
39	48	1·19	...	...	...	40	44	1·59	...	...	...	42·5	44·5	1·55	...	...	...	...	...	...	...	...	...
50	57	1·31	...	...	...	50	56	2·01	50	59	2·40	...	...	...	...	...	...	...	...	...	...	...	...
60	70	2·24	...	...	...	60	66	2·65	...	...	...	57·5	63·5	2·06	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	70	76	3·34	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	85	95	5·34	80	89	4·54	80	89	4·7	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	90	99	5·65	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	121·5	133	8·82	...	...	...	100	110	5·94	...	...	...	...	...	...	...	...	...	110	121	6·50
...	...	...	154	165	12·25	...	...	...	147	158	10·12	...	...	...	154	160	11·0	...	...	...	...	...	...
...	...	...	178	191	16·37	...	...	...	172	184	13·27	...	...	...	196	200	13·5	...	...	...	...	...	...
...	...	...	250	267	26·51	...	...	...	...	...	...	...	...	...	219	225	15·0	...	...	...	...	...	...
...	...	...	290	305	27·66	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

will be sufficient for the shaft mains, and the following dimensions for the various branches:—

In cross drivages and drainage galleries . .	3 inches.
In winzes and inclines	2 ,,
In working galleries	$\frac{4}{5}$ to 1 inch.

Only in the event of the sprinkling mains being used for the transmission of power are larger sizes—up to about 10 inches—necessary.

The usual material for the smaller pipes is wrought-iron, and for the larger ones steel (Mannesmann tubes, spiral-welded, and patent-welded wrought-iron gaspipe).

The pipe joints consist of loose flanges.

Cast-iron pipes, which are less liable to rust than those of steel or wrought-iron, are seldom used, and then only for the larger sizes (over 10 inches). In this case the flanges at the joints are fixed. The pipes are in lengths of 12 to 16 feet.

It is advisable to coat the pipes inside and out with red-lead paint, hot linseed oil, or asphaltum. Galvanising also helps to prevent rusting.

In galleries the pipes are laid close up against the roof, and are supported by wooden pegs or iron hooks; those of smaller diameter may also be suspended from the timbering by wire loops. In laying the pipes a level must be constantly employed, so as to keep them horizontal or at an almost uniform slope throughout the gallery.

To prevent breakages of the pipes in galleries where the rock is not of a firm character, short lengths of rubber piping lined with coiled wire are inserted at intervals.

It is a bad practice to bend the pipes cold for passing round curves, a better plan being to fill them with sand and then apply heat. Where a right-angle turn has to be made, junctions of cast or wrought-iron are best; and 3-way (T-piece) or 4-way connections should be inserted for branches, and attachments for valves, hose lengths, etc. Valves are preferable to taps for cutting off the supply, in order to diminish the suddenness of the cut-off and the attendant risk of shock and breakage. These valves cost from 10s. to 26s. apiece, according to the diameter (1 to $3\frac{1}{2}$ inches).

Rubber hose, $\frac{1}{2}$ inch in internal diameter, $\frac{1}{4}$ inch thick, and in lengths up to about 60 feet (costing 1s. to 1s. 9d. per yard run), is used for sprinkling. This hose is permanently attached to the supply-pipe in working places, and is connected to hydrants in the headings wherever required.

35. Wetting the Coal Face.—The Meissner system of wetting the

coal face consists in drilling one to three holes to a depth of 40 inches in the coal during the shift preceding that in which the coal is to be worked. A ½-inch iron pipe is then fitted into each hole by the aid of a wooden washer, and connected up with the supply-pipe, the water pressure being then allowed to act on the coal for eight hours. In this manner the coal is so completely permeated with moisture that the formation of dust in winning is precluded. This method, however, does not act in the case of very hard or fissured coal, in which event the working face and the won coal must be the more frequently and thoroughly sprinkled with the hose.

In inclines, haulage ways, etc. hydrants are attached to the supply-pipe at intervals of about 50 to 80 yards. To these hydrants are connected lengths of hose sufficient to reach half-way along, and by means of these latter the men charged with the sprinkling wet the walls, floor, etc., and swill away any accumulations of coal dust. This operation is repeated every two to three days, a longer interval (a week) being permissible only in special cases.

In headings connecting two adjacent working sections, wet zones, 50 to 80 yards in length, are provided every 70 to 100 yards, in order to restrict any explosion of firedamp or coal dust to the originating centre. The efficacy and utility of such wet zones has been amply confirmed by experience.

Cost of setting up and working Installations for Sprinkling.

36. The cost of installation of a system of sprinkling pipes amounts to 2s. 3d. to 3s. per yard run; or up to 4s. where larger pipes are used for transmitting power.

According to Droege, the working expenses of such installations in the Saarbruecken district (1895–1896) ranged from 6s. 6d. to 13s. 4d. per 100 tons of coal raised, and were highest where the action of heavy rock pressure necessitated frequent repairs.

Advantages and Disadvantages of sprinkling Coal Dust.

37. In addition to preventing explosions, the sprinkling of the working face and the wetting of coal dust in the galleries is also attended with other considerable advantages in the working of the pit. In the first place, shot firing, which in many places would otherwise be dangerous and prohibited, can be resumed without objection when

sprinkling is practised. The removal of coal dust from the air of the mine makes the latter far healthier for the miners, and the disease known as "coal lung" disappears. Sprinkling also considerably reduces the very high temperature usually prevailing in deep pits—a result that is not only agreeable but also conducive to health. The sprinkling pipes can also be used for transmitting power for the purposes of separate ventilation, etc.; and, furthermore, extensive and thorough sprinkling diminishes the frequency of pit fires, whether arising from spontaneous ignition, malice, or negligence. At the same time, should a conflagration break out, the water and means for its prompt extinction are ready to hand.

Nevertheless, sprinkling has also certain disadvantages. Where the rock is clayey in character, swelling of the floor and its attendant inconveniences are caused or furthered; the coal is also often made dirty and unsightly, and in winter is rendered liable to freeze in the haulage tubs, storage towers, and railway trucks, by reason of the large amount of water present. These disadvantages, however, are not very weighty, and must be put up with.

Other Precautions for preventing Explosions in Fiery and Dusty Mines.

38. In the same manner that a barrel full of powder will not explode unless admission is gained by an igniting spark, so also is an explosion of firedamp or coal dust impossible without ignition.

Up to now we have considered the means whereby firedamp can be removed from the pit without injury, and the accumulation of inflammable coal dust prevented; nevertheless, in order to prevent the unforeseen failure of these precautions, it is essential that there should be no chance of the dangerous substances in question being ignited.

It has been already stated that the ordinary open miners' lamps must be replaced by safety lamps in fiery mines. In this latter class of lamp the flame is surrounded by a strong and well-cooled glass chimney (cylinder), in order to facilitate the transmission of light to the outside. Of course the oxygen necessary to support combustion is derived from the outer air, but the admission and discharge passages are interrupted by fine wire gauze, which is doubled in the newer forms of safety lamp. By this means the flame is prevented from deflection by strong draughts, and at the same time is incapable of producing ignition of inflammable gases in the outer air. Furthermore, even

though these gases penetrate with the air into the interior of the lamp, and there become ignited, the ignition cannot be transmitted to the outside, since the burning gases are so far cooled in passing through the double gauze as to be incapable of communicating the ignition to the outer air and thus inducing an explosion.

At the present time the greatest amount of safety against the ignition of firedamp mixtures is afforded by the Friemann and Wolf benzine lamp, with inside lighting device and double gauze cylinder (shown in Figs. 6 and 6*a*), and consequently this lamp is more and more replacing the rape (colza) oil lamp. Such benzine lamps give a better light than rape oil, and a flame perfectly free from smoke and soot; the light is cheaper; the lamp when extinguished can be immediately and safely relighted without opening; the wick does not require cleaning; the presence of 1 per cent. of methane in the air can be readily detected; the lamp flame does not strike through, nor will it ignite a 9 per cent. firedamp mixture in the most powerful draught (air velocity 60 feet per second).

Dangers of Blasting in Fiery Mines.

39. A great source of danger in fiery and dusty mines resides in the operation of blasting; and a careful investigation of the causes of firedamp explosions in various countries has shown that shot firing is the usual cause of ignition in such accidents.

Ordinary black powder has proved especially dangerous in this connection. Although this powder explodes at a far lower temperature than the so-called high explosives, which are prepared by nitrating organic substances, it generates such a large volume of inflammable and also very poisonous gases that the absolute prohibition of this powder in its present form is highly necessary, not only in fiery pits, but for all underground work whatever, unless an addition of at least 78 per cent. of saltpetre be made to the charge. According to Demanet (*Traité d'Exploitation des Mines de Houille*, 2nd ed. vol. ii. p. 61), the gases liberated by the combustion of black powder low in saltpetre consist of—

32·13	per cent.	CO_2.
33·75	,,	CO.
19·03	,,	N.
7·01	,,	H_2S.
5·24	,,	H.
2·75	,,	CH_4
100·00	per cent.	

Of these gases 48·84 per cent. are combustible, and 40·76 per cent. exceedingly poisonous.

Since the combustion of 1 gramme of such powder furnishes over 300 cubic centimetres of gas, 1 pound of the powder will contaminate 36 cubic metres of pit air with CO and H_2S to such an extent that the mixture will quickly prove fatal to human life.

It is further evident that an explosive generating such a large volume of combustible gas cannot contain nearly sufficient oxygen to oxidise this gas, and therefore urgently requires the addition of a carrier of oxygen. Moreover, the introduction of combustible gas from powder into a pit air containing an insufficient amount of firedamp to be inflammable may easily render the latter explosive.

Powder with a deficient proportion of saltpetre or oxygen is unsuitable for the preparation of fuses.

However, even the high explosives made from nitroglycerin do not afford sufficient protection against the ignition of firedamp and coal dust, especially when the shot holes are overloaded or give blown-out shots, or in the event of accidental explosion of the explosives in the mine. Pictures taken at the instant of shot firing with these high explosives show a decided external flame, from which it may be concluded that firedamp mixtures and coal dust could be ignited thereby under certain circumstances. On this account the practice has arisen of tamping the shot holes with water cartridges, or of mixing crystalline salts with the explosives themselves, in order to cool down the ejected combustible gases formed by the firing of the charge, and thus prevent the formation of a flame. In addition, there have been introduced, for use in fiery mines, so-called safety explosives (free from nitroglycerin), which explode at relatively low temperatures (1500° to 1800° C., and exceptionally up to 2000° C.), consist mainly of ammonium nitrate and aromatic hydrocarbons (benzol, naphtha, aniline, resins, fats, etc.), and can only be fired by very powerful detonating caps, but not by direct flame or red-hot iron. The conveyance, handling, and storage of these explosives are free from danger. The larger the proportion of hydrocarbons used in their manufacture, the more powerful the explosives; hence the more readily do they produce an external flame when fired, and therefore the lower the degree of safety afforded. On the other hand, the safety is increased by additions of ammonium oxalate, or salts of chlorine, bromine, and iodine, which at the same time diminish the explosive power.

In Saarbruecken the best results have been obtained with the safety blasting powder of the Koeln-Rottweiler Pulverfabrik, dahmenite and

new westphalite coming next; in the Maehrisch-Ostrau district, progressite has proved the best. Demanet gives the following list of safety explosives: Roburite, ammonite, bellite, securite, westphalite, antigrisou Favier; none of which, however, afford absolute safety against the ignition of firedamp mixtures. They can only be regarded as relatively safe, provided the amount of the charge in each borehole does not exceed 250 grammes (9 ounces).

When the safety-lamp test reveals the presence of firedamp at a working place, shot firing should be unconditionally prohibited there. In all the mining districts of Germany this question is dealt with minutely by the regulations of the mining police.

Shot Firing without Danger in Fiery Mines.

40. It would naturally be useless to prescribe the exclusive use of safety lamps and safety explosives in fiery mines were permission given to fire the shots by means of a naked light, ordinary fuse, or burning straw. No sufficient degree of safety would either be assured by lighting the fuse with tinder kindled with flint and steel, since the fuse itself throws off sparks of flame in burning, and is therefore capable of igniting firedamp. Moreover, the so-called safety lighters, enclosed in incombustible wrappers, cannot be classed as absolutely safe when they contain a powder core.

Electrical Ignition.

41. In any case the best method of firing the blasting charge is by electricity, the safest being the so-called incandescent (or glow) lighter, actuated by an induction machine (Siemens & Halske type, for instance). In Maehrisch-Ostrau permission is granted to fire shots in gassy mines with Lauer's friction igniter or Tirmann's percussion igniter, which method is said to be quite innocuous (Koehler).

The central igniter of Jarolimek, consisting of a detonating cap fired by means of compressed quicklime and water, is also characterised as safe.

Explosions of Gas and Firedamp caused by Shaft and Pit Fires in Fiery Mines and in Mines working Anthracitic and Sintering Coal.

42. Pit fires are in themselves a very dangerous foe to the miner. They are liable to break out in shafts and underground workings, and

may be started as a result of carelessness or malice. As already mentioned, pit fires also occur as a result of spontaneous ignition of the coal, and are unfortunately of very frequent occurrence in mines with thick seams of clod coal, *e.g.* those of Upper Silesia. Seams of gassy long-flame coal are less liable to spontaneous ignition, since here the pores of the coal are filled with methane, which retards the absorption of oxygen from the air, and consequent oxidation. On the other hand, fires due to carelessness or malice are just as readily caused, as in other pits, with non-caking coal; or, finally, may result from explosions of gas or coal dust.

The condition into which such a pit then falls is one of extreme danger, since it is almost impossible to barricade the fire in the immediate vicinity of its seat by means of dams of masonry, etc., as this would entail a cessation of the ventilating current, leaving the disengagement of gas unrestricted, or even increased, as a result of the fire. The consequence would be the production of secondary explosions, attended with the gravest danger to the men engaged in dam building. In such cases the only thing that can generally be done is to submerge the seat of the fire for some time, which usually means the flooding of the whole pit; or the shafts may be hermetically closed and working discontinued until the fire has been suppressed, and the seat of same sufficiently cooled down. This cooling, however, cannot be successfully effected so long as the internal pressure, recorded by a pressure gauge, considerably exceeds that of the atmosphere. For the same reason, the burning section cannot be reopened until the excess pressure has disappeared.

If a revival of the fire be feared, in reopening a gassy pit that has been closed on account of fire, as was the case, for example, at the Wilhelm shaft of the Kaiser Ferdinands-Nordbahn Colliery at Polnisch-Ostrau in 1884, the sole way to carry on the recovery work is by the aid of the Von Bremen rescue apparatus, the ventilation of the pit being stopped, and the air supplied to the workmen through pipes and hose.

In pits working anthracite and caking coal seams no inflammable gas is liberated at the ordinary temperature; but at higher temperatures, *i.e.* in the case of a pit fire, this liberation may easily occur, and in such event gas explosions may result, even though merely in a lesser degree. As a matter of fact, such explosions have been observed in Upper Silesian pits.

Special caution is necessary in visiting the headings in the vicinity of masonry dams erected to isolate a burning section, since in these

localities accumulations of inflammable gas are particularly liable to occur, especially against the roof, owing to the escape of gas through cracks in the dams, coal, or surrounding rock. For this reason, such spaces near dams should not be visited with naked lights, but should be tested with safety lamps. The chemical composition of the gas escaping from burning sections of pits working sintering coal is analogous to that of crude coal gas, and in any event contains a large amount of methane, this being lighter than ordinary air, and collecting, as has been said, near the roof of the adjacent galleries. Owing to the presence of carbon monoxide, the gas escaping from the seat of a pit fire is exceedingly poisonous. It should not, however, be assumed that such gas owes its explosive character to carbon monoxide, the density of this latter being very little greater than that of the air, whereas the fire gas is apparently much lighter. To render fire gases inflammable or explosive from CO, they must contain over 12 to 15 per cent. of this constituent; at least, such is found to be the case in the gases from blast furnaces. As CO is of nearly the same density as atmospheric air, and therefore readily diffusible therein, it follows that such a high percentage would prove fatal to all life in the vicinity of the burning section, since we have seen that even 0·3 per cent. of this gas is fatal to the human organism. On the other hand, the largest proportion of CO that has ever yet been detected in fire gases is less than 3 per cent. (See Lamprecht's *Recovery Work after Pit Fires.*[1])

Precautions for Obviating and Repairing the Injurious Effects of Firedamp Explosions.

44. Properly speaking, all workers in fiery mines should be obliged to protect the nose and mouth with respirators of fine metal gauze, like the wire gauze of safety lamps, in order to prevent, in case of an explosion, the inhalation of the fiery gases into the air passages and lungs, and guard against the grave internal injuries inevitable thereon. This inhalation frequently occurs in cases of firedamp explosions, and is known among English and Belgian miners as "swallowing the fire." At all events, every one who is obliged to remain any time in a fiery pit should be provided with a wet cloth, so that he can protect his mouth and nose when an explosion is feared (*e.g.* in shot firing), or when the approach of a fire is observed. This wet cloth will play the same part as the gauze of a safety lamp, and prevent

[1] Published by Scott, Greenwood & Co. London, 1901.

the flame penetrating the mouth and air passages, or keep these organs from being obstructed by smoke and dust.

Firedamp explosions are attended with injurious and destructive consequences—

(1) Owing to the resulting dangerous gases (afterdamp), and the excessive consumption of the atmospheric oxygen, whereby the miners are liable to be poisoned and suffocated.

(2) Through the high temperature following on the combustion of firedamp and coal dust, whereby the miners may be burned and injured, and pit fires caused; and

(3) Owing to the mechanical force, exerted by the explosion, injuring or killing the miners and any animals engaged in the pit, as well as destroying and throwing down the pit timbering, causing falls in the headings and other spaces, damage to the ventilating appliances, especially the air doors, brattices, air crossings, and finally also to the shaft appliancès, the ventilating machinery, the air conduits, and the shaft doors.

The Chemical Composition of Afterdamp.

44*a*. The chemical composition of afterdamp—the presence of which is generally revealed by the dense smoke and dust following an explosion—has not yet been accurately determined by analysis, it being extremely difficult, if not impossible, to obtain samples of the same immediately after an explosion, by reason of the exceedingly poisonous nature of this gas. This composition is sure to be very irregular, owing to the fact that the amount of the firedamp and coal dust burned during an explosion fluctuates from place to place.

In any given locality in the pit, however, there will always be more firedamp near the roof than near the floor. Moreover, the firedamp will at one time be predominant, so that the atmospheric oxygen present will be insufficient for the complete combustion of the methane, whilst at another time the latter will be lacking, and the oxygen therefore in excess. Again, owing to the specifically lighter nature of the firedamp, the gas and air are never, or very seldom, thoroughly mixed.

It may, nevertheless, be accepted as a fact that undiluted afterdamp invariably contains a considerable amount of carbon monoxide, and is therefore quickly fatal to animal life. Even when diluted and mixed with the air, which rushes in from adjacent headings (unaffected by the explosion) in consequence of the condensation of the water vapour produced by the explosive reaction, the afterdamp is always still sufficiently poisonous to generally cause the death of any person coming within its influence.

According to Dr. Haldane, afterdamp may be assumed to contain about 80 to 85 per cent. of nitrogen, 12 to 14 per cent. of oxygen, 4 to 6 per cent. of CO_2, 0·6 to 1·5 per cent. of CO, together with small quantities of sulphurous acid, sulphuretted hydrogen, and unconsumed methane. The percentage of oxygen, however, must often exceed 17·6 per cent., since, in many cases of explosions where miners have been found overcome by afterdamp, their lamps have been discovered either still alight or else with the entire supply of oil consumed.

Behaviour of the Miners in Afterdamp.

45. The first problem now arising is in what manner and by what line of conduct it is possible for miners overtaken by an explosion to best make their escape and preserve their lives. Certain experiences made in this connection tend to show that persons unfortunate enough to be so overtaken are able, by calm consideration and procedure—and provided they are not exposed to the first effects of the accident—to do much more for their own preservation than can be effected by the rescue-parties which — for the most part too late — hasten to their assistance. Now, careful investigations and observations into the great firedamp accidents which have occurred — principally in England — during the past few years, show that only a small proportion of the total fatalities are due to the primary destructive action of the explosion, the greater part — from 75 to 90 per cent. — succumbing afterwards to the effects of afterdamp, mostly during the flight towards the shaft.

On this account, the men should be urgently recommended to throw themselves flat on the floor on the approach of the explosion flame; and, provided they are not directly in the midst of the smoke and fumes at the site of the explosion itself, they should remain in that attitude, in the first place to avoid injury from flying objects, but mainly in order that they may be able to breathe the air near the floor,—because at the outset, after an explosion, the poisonous gases are still warm, and therefore collect near the roof, whereas the air against the floor is still cool and fresh.

The following instance bespeaks the accuracy of this advice:—

On the occasion of an explosion in No. 8 pit at the Tylorstown Colliery, the rescue-party found a number of mice still alive and running about in a part of the pit where the whole of the miners had been killed by poisonous gas (carbon monoxide). These mice had escaped the injurious influence of the afterdamp through being naturally on the

floor, though, as we know, such small animals are more susceptible to poisonous gases than man.

It must also be remembered that men breathe much less when at rest than when in active motion, and can therefore exist longer in foul air by remaining quiet than by a hasty flight. In many instances the men in a working place that has not been reached by the flame of the explosion could save themselves by setting up a brattice to close the heading leading to the portions of the workings laden with afterdamp, and in this manner remain until reached by the rescue-party after ventilation has been re-started; whereas by running away immediately they would certainly encounter and be overcome by afterdamp. For it is certain that, in the case of an explosion extending throughout an entire section of the pit, the flame will traverse the main haulage ways and drainage galleries through which the men would have to pass on their way to the shaft; and that consequently these ways will be laden with afterdamp until such time as the latter is removed by the restored ventilating current. Whilst it is true that, with the recently introduced safety lamps with internal lighting devices, it is easy to relight the lamps after they have been extinguished by an explosion (provided, of course, the atmosphere is not of such a character as to preclude all combustion), nevertheless this should not mislead the men into making a heedless flight towards the shaft along a way where death is surely waiting them. Furthermore, it should be remembered that an explosion can be—and very often is—followed by the appearance of gaseous mixtures, which contain carbon monoxide in fatal amount, though they will still support the combustion of the lamp. As already stated, the presence of the smoke generated by the explosion affords the sole means of ascertaining whether one is in the midst of a fatal gaseous mixture, or near same. When this is the case it may be possible to find safety in a side gallery, out of the path of the explosion.

Means of bringing Help from Outside to the Imprisoned Miners after a Firedamp Explosion.

46. To ensure that the aid sent to the imprisoned miners from outside after an explosion will be effectual, the first thing to be done is to restore—if possible in an increased degree—the ventilation that has been interrupted by the mechanical effects of the explosion; this with the object of driving the afterdamp out of the underground workings in the shortest possible time. Unless the rescue-parties are to be sacrificed uselessly, they must not enter and traverse the pit except

along with the fresh air current, or after they have been provided with respiratory (rescue) apparatus. Should the pit be provided with a spare ventilating fan, this must be set to work as well, in order to strengthen the current. As a rule, the only part of the pithead gear damaged by a powerful explosion is the cover of the upcast shaft, and for this reason a supply of suitable materials should always be kept at hand for repairing the same immediately. Movable caps, resembling the bell of a gasometer, and guided in the same way, will probably be lifted by the force of the explosion, and then automatically reclose when the force has spent itself.

It is also advisable to provide several large flap valves in the culvert leading from the upcast shaft to the fan, which flaps will open outwards when an explosion occurs, and then close again of themselves as soon as the pressure of air from the shaft ceases to act.

The next step (one of special importance) is to send the rescue-party down as quickly as possible, and to provide for the immediate repair of the damaged ventilation appliances in the pit, especially the brattices, air doors, and air crossings, since, until this is done, the ventilating current will traverse the shortest way from the intake to the upcast shaft, leaving all the other workings untouched. It may also happen that the winding shaft or the cage has suffered damage, thus greatly retarding the descent of the rescue-party. In order to reduce the possibility of this accident to a minimum, the shaft and the surrounding headings and pass-byes, for a distance of at least 100 yards, must be kept constantly free from accumulations of coal dust and thoroughly wetted. Sprinkling the shaft affords at the same time an effectual and highly necessary protection against the dangerous and injurious outbreak of shaft fires.

When the intake and upcast shafts are situated very close together, any headings leading from one to the other must be made narrow, and provided with very strong air doors.

All points respecting the fitting out and performance of rescue work must be accurately defined and practised beforehand, and be properly made known to the officials of the mine. The men of the rescue-parties should also be made familiar in advance with the dangers attending exposure to the influence of afterdamp, and should be acquainted with the indications which the safety lamps are capable of furnishing.

Safety lamps are extinguished by the presence of 3 to 4 per cent. (5 per cent. at the most) of methane in the air, or by 15 per cent. and over of carbon dioxide; as also when the percentage of oxygen falls below 18 per cent. (17·6 per cent.). If a mouse or two be taken

along with the party, the latter will then be in a position to detect the presence of a dangerous proportion of carbon monoxide in the pit air, or afterdamp, as already described. In the case of oil-burning safety lamps, the presence of 1 per cent. of CO will be revealed by the appearance of an aureole round the flame; but this seems to be less reliably shown by benzine lamps. Moreover, as already stated, 1 per cent. of CO in the air will prove fatal to human life in a very few minutes.

The rescuers should take good note of places where the timbering has been dislodged, and where roof falls have occurred or are imminent; and under certain circumstances these defects should be temporarily repaired as well as possible, or the places of their occurrence avoided.

It is also important that the rescue brigade should take with it the necessary implements and materials for repairing damaged air doors, air crossings, etc.

The care of the sick and wounded found in the mine should, as far as possible, be left to the charge of persons having special knowledge in such matters; of course they must have at disposal a supply of medicaments and restoratives, as well as a sufficient number of bearers, litters, etc., in order to usefully render Samaritan service.

Respiration and Rescue Apparatus for entering Workings laden with Injurious Gases.

47. Respiration and rescue apparatus are employed in certain manufacturing industries and by fire brigades; but mainly in mining, for the purpose of effecting an entrance into workings, etc. filled with an irrespirable atmosphere, so as to perform work therein for a longer or shorter period, or to rescue miners who have fallen unconscious and are endangered by poisonous gases there. Almost without exception, miners are brought into this unfortunate condition as a result of explosions of firedamp or coal dust, or fires in the shaft or the pit.

The oxygen necessary for respiration may then be derived—

(*a*) Either from the surrounding atmosphere, or

(*b*) From a distance.

If the oxygen be taken from the surrounding air, which at the same time contains irrespirable gases, it is above all essential that the oxygen itself is present in sufficient quantity therein, the next indispensable condition being the possibility of preventing the simultaneous entry of the injurious gases into the lungs of the person breathing this air.

If, however, the oxygen needed for respiration in an ill-ventilated place has to be brought from elsewhere, this can be done in two ways, namely, by either supplying the pure air through a pipe or tube, or else providing the user with a vessel charged with compressed air, or, better still, oxygen.

The apparatus in the former case consists of fixed pipes—an arrangement well adapted for use in cases where prolonged work has to be performed in an irrespirable atmosphere at a given spot. Though in such event there is no limit to the time the apparatus can be used, the user is restricted in his movements by the length of piping provided.

The other kind of apparatus (the portable) is best adapted for rescue work in case of pit accidents, since the user is allowed perfect freedom of movement to great distances, though the time limit is fixed by the amount of the oxygen contained in the apparatus.

The fixed-pipe apparatus can be supplied with air by suction or by a force-pump. In the former case the air is drawn by the user through a length of pipe not exceeding 50 yards at the most, and usually measuring half that distance. This pipe is about 1 inch in diameter, and connects the mouth of the user with the place whence the supply of air is to be drawn.

When pumps are used to force the air through the pipe, the above distance can be increased to 100 yards, the pump supplying air being situated in a place where the air is fresh. Compressed air may also be used, and in such event the pipe may extend for distances up to about 200 yards, and be fitted with connections for the attachment of branch hose at suitable intervals.

Whatever apparatus be used, it is indispensably necessary that measures be taken to prevent the entry of the surrounding impure atmosphere into the wearer's lungs. In the apparatus now in use this end is attained by the user breathing through a mouthpiece at the end of the tube, the nose being kept shut by a clamp; or else the face is entirely covered by a mask, which keeps out the foul air and is provided with a glass window in front. In the newer forms of apparatus the face mask is provided with a helmet resembling that of a diver, covering the entire head, and affording protection against the influence of heated air and the like.

The nose clamp and the goggles, also necessary to protect the eyes when working in smoke fumes, are very inconvenient, and are easily displaced when the wearer is at work or afflicted with copious perspiration; and, moreover, the mouthpiece impedes speech, and may easily be dislodged during work or as a result of coughing, thus endangering the

wearer, on which account it will be evident that the use of such apparatus as are provided with a mask, which obviates all these risks, is to be preferred.

The remark made under A, to the effect that oxygen may be derived from the surrounding air when breathing in dangerous gases, does not imply that the rescuers, hastening bravely to the succour of imprisoned comrades, should enter an atmosphere of poisonous gases without any protection and with uncovered mouth and nostrils, but has reference to the provision of appliances to be interposed between the organs of respiration and the foul atmosphere, in order to keep the injurious gases away from the lungs. It has been already mentioned that in such cases the mouth and nose should at least be covered with a damp cloth, to keep out smoke and dust, and thus prevent mechanical obstruction of the air passages.

The Robert Respiration Apparatus.

48. Very little superior to a wet cloth in point of efficacy is the oldest form of respiration apparatus—that of Robert. This consists of a perforated sheet-metal cylindrical vessel, carried in front of the wearer by means of a belt, and containing a sponge saturated with milk of lime. A pipe leads from the interior of the vessel to the mouth of the wearer, so that, in the act of inhalation, the outer air is drawn through the sponge, the carbon dioxide being absorbed and retained by the milk of lime.

As will be gathered from what has been already stated, the amount of carbon dioxide present in afterdamp from explosions of firedamp or coal dust, or in the products of combustion of pit fires, is rarely so extensive as to cause suffocation, even on prolonged exposure thereto, the greatest risk being due to the presence of the still smaller proportion of carbon monoxide in the air. Now, milk of lime has not the slightest retentive affinity for carbon monoxide, so that in such cases the Robert apparatus is incapable of affording more than a slight degree of protection, if any at all.

It has been averred—and this opinion is shared by Dr. Haldane—that no substance is known to be capable of absorbing and fixing CO. This, however, is incorrect, a solution of cuprous chloride (Cu_2Cl_2) in hydrochloric acid taking up this gas readily and in large amount (Lohrscheid). It would therefore be worth while to test this property by means of an apparatus similar to that of Robert, but using cuprous chloride to saturate the sponge.

FIXED RESPIRATION APPARATUS.

49. The respiration apparatus of L. von Bremen (Kiel) is shown in Figs. 9, 9*a*, and 9*b*. It chiefly consists of a metal case A, weighing about 1 pound, and suspended on the wearer's back by means of a shoulder strap and a belt. The case contains two rubber valves, *a* and *b* (Fig. 9*b*), the former being the inlet valve, and the latter the discharge valve. Both are made of the finest soft caoutchouc, so that the two plates of which they are composed fit easily together in an air-tight manner. Each of the rubber valves is slipped over the end of a corresponding tubular attachment fitted to the metal case. The slightest pressure on the elastic valve plates causes them to separate, so that the air can pass between them, whereas the gentlest excess of external pressure immediately causes them to reclose.

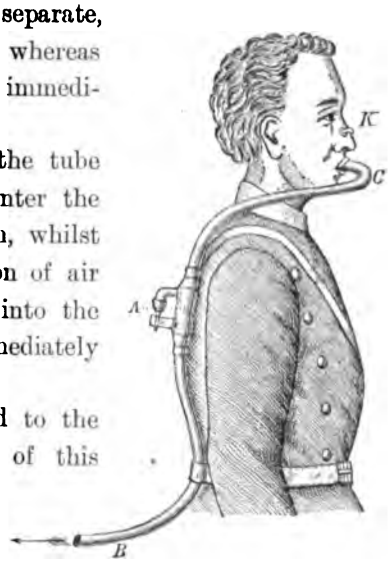

FIG. 9.

In the act of inhalation through the tube C the valve *a* allows the fresh air to enter the case A and flow into the wearer's mouth, whilst the valve *b* opens during the exhalation of air and allows the expelled gases to escape into the outer air, whereupon the valve itself immediately recloses.

By means of a 1-inch pipe attached to the lower end of the case A the wearer of this apparatus is enabled to breathe at distances up to about 50 yards from the source of fresh air.

Fig. 9*c* shows a pair of goggles, which also act as a nose clamp, and are used when the wearer has to enter an atmosphere of pungent smoke fumes, an ordinary nose clamp being sufficient in other cases. The body of the goggles consists of a rubber bag, which can be inflated by means of a small tube *s*, and tap *v*, after the apparatus has been fastened round the head by the small strap shown in the drawing, whereupon it fits tightly against the face. Small slides are provided for cleaning the glasses.

The complete apparatus consists of an intake tube C, with mouthpiece, a case A, with two rubber valves *a* and *b*, a nose clamp K, or goggles, a shoulder strap, and a waist belt. Two extra mouthpieces, two rubber valves, and two simple nose clamps are included in the set. The cost is 50s. without the goggles, or 72s. 6d. with the latter.

The ordinary piping costs about 4s. 6d. per yard run, or 8s. if covered with pure rubber.

The von Bremen Smoke Helmet, with Pipe and Jacket. (Fig. 10, Plate IV.).

50. This apparatus, which has proved highly useful for prolonged work in irrespirable gases at a fixed station in the mine, consists of a

Fig. 9a.

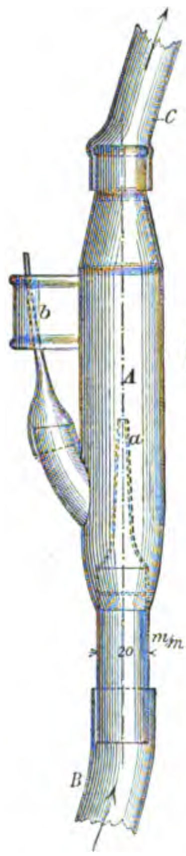

Fig. 9b.

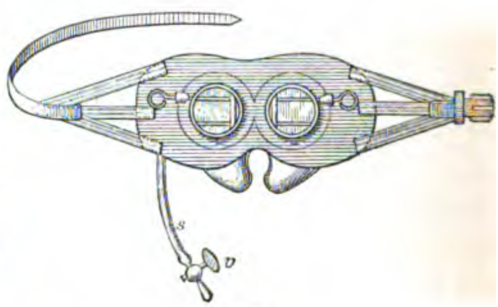

Fig. 9c.

light leather jacket attached to a wicker helmet stiffened with Spanish cane, and provided in front with a glass plate which opens like a window. After the jacket has been put on, it is fastened in an air-tight manner by means of a waist belt and straps on the sleeves, so as to prevent the entrance of dangerous gases. The pure air is introduced, under a pressure of about 0·2 atmosphere (1·2 atmospheres absolute pressure), through a $\frac{1}{2}$-inch pipe debouching at the back of the head, from an available source, and is carried through the helmet in three air passages, which

open in the form of slits in front of the mouth. The discharged air makes its escape partly through leakages in the jacket, partly through a gauze sieve in the helmet. A slight excess pressure must always be maintained inside the jacket and the helmet, to prevent an inrush of poisonous gases from outside. The air supply is delivered through piping by means of a double-action lever air-pump (B, Fig. 10), or, better still, by a double-cylinder air-pump of the kind used with diving gear (Figs. 11 and 12).

The admission pipe may also be connected with a compressed-air supply, when such is available in the pit, the air in this case being delivered by a compressor. An arrangement of this kind was used in the recovery work at the Wilhelm shaft of the Kaiser Ferdinands-Nordbahn Colliery (Polnisch-Ostrau) in 1884, and described by Meyer in the *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1887.

This apparatus also proved useful at Count Larisch's colliery, Karwin (compare above journal, 1895).

51. In place of a helmet entirely covering the head, the same maker supplies the apparatus illustrated in Fig. 12. In this case the wearer's nose is simply closed with a clamp, and respiration is performed through a case mounted on his back, similar to that described in Fig. 10. This type, however, has not met with any extensive application in practice.

There is not very much difference between the Bremen apparatus and the Stolz rescue mask (Fig. 13), or the Mueller smoke helmet (Fig. 14). The Stolz mask is made of brass, and fits close against the face by means of a pad of rubber placed round the edge. Two openings, covered with fine wire gauze, are provided for the eyes, and through these apertures the expelled air makes its escape along with any excess of air from the supply-pipe. This pipe is divided, at the back of the wearer, into two branches, which are attached to the sides of the mask.

52. The Mueller smoke helmet (Fig. 14; see also Lamprecht's *Recovery Work after Pit Fires*) is manufactured by the firm Neupert's Nachfolger, Vienna. It is made of deerskin, and the opening in front of the face is covered with a double layer of wire gauze, through which the discharged air escapes. The lower edges of the mask are drawn tight, by chains passing under the wearer's arms, to prevent any influx of foul gases from the outside. The complete mask, with chains, spiral spring, and 40 yards of rubber pipe, costs £6, 10s.

Electric Lamps for Use in Dangerous Gases.

53. Portable electric lamps, deriving their current from batteries or accumulators, are now generally and successfully used for lighting in

irrespirable gases. A very useful type of electric accumulator lamp is the Bristol, or that of the Berlin Akkumulatorenfabrik employed in the Shamrock Pit (Westphalia).

PORTABLE (KNAPSACK) RESCUE APPARATUS.

54. As far back as 1876 a rescue apparatus of the knapsack type, fed with compressed air, was introduced by L. von Bremen. The time limit (25 minutes) was, however, too short for the successful performance of rescue work in irrespirable gases.

Subsequently compressed oxygen was employed for the same purpose, with better results; well-known specimens of this type being the oxygen apparatus of Schwann (Liège) and Fleuss (London). Though successfully used for rescue work in English collieries on various occasions, the original Fleuss pattern did not altogether answer in the Saarbruecken district, and had to be modified. In Maehrisch-Ostrau, also, according to a report by J. Mayer, it was found, in the course of tests with the Fleuss apparatus, that the same could only be worn for about 10 minutes, before considerable oppression supervened. Recently the Fleuss apparatus has been considerably improved by Winstanley, so that its future now seems assured, the more so because of the greater ease with which a supply of compressed oxygen can now be obtained. The cost, however, is rather high, namely, £13.

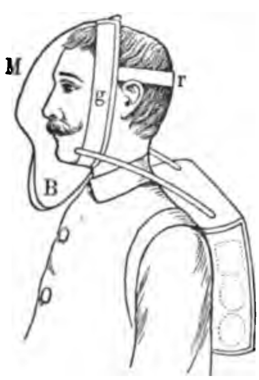

FIG. 15a.

The Giersberg portable rescue apparatus (1901 pattern), Figs. 15*a* and 15*b*, for use in irrespirable atmospheres, represents a distinct advance in the designing of this class of apparatus, inasmuch as the oxygen supply is uniformly regulated and the purification and return flow of the exhaled air are effected by the power stored up in the compressed oxygen.

It is well known that even men who are skilled in the use of oxygen respiration apparatus are only too prone to open the oxygen valve unduly wide, thus inducing too high a pressure within the mask or air bag, and thereby increasing the difficulty of breathing and unnecessarily shortening the working period of the apparatus.

In the Giersberg apparatus a similar mask to that of the Neupert apparatus (Figs. 19–19*a–c*, Plate VI.) is used, the illustration in Fig. 15*a* being a mere outline sketch. The mask M is made to fit air-tight against the face by means of a pneumatic rubber tube *g*, and is held fast by a strap *r* passing round the back of the head. The

wearer has no difficulty in hearing and communicating with persons near by.

The lower part of the mask is widened below the chin into a leather-covered pouch B, into which the exhaled air sinks, and which also contains the mouth of the supply and discharge tubes *a* and *c* (Figs. 15*a* and 15*b*).

All the rest of the apparatus is enclosed in a knapsack, and carried on the wearer's back. The two oxygen bottles SS are fastened together and are connected by the metal pipe *a* with the wearer's mouth. The pipe *a* is fitted with a pressure-reducing valve and a pressure gauge.

The pressure gauge would seem to be out of the wearer's sight—a defect, however, easily rectified by providing a flexible metallic gauge pipe, which could be attached to *a*, and would enable the gauge to be carried in the pocket. The tube *c* debouching at the other side of the mask conveys the exhaled air and carbon dioxide to the absorption vessel C, whence, after purification, it is returned to *a* through the pipe *b*, being drawn therethrough by the injective action of the oxygen flowing from bottle S into the mask. Solid soda-lime is the absorbent used in the vessel C. This material allows the air to filter through, and is easily replaced when exhausted. The apparatus being automatic, can be relied on to work for a given period (2 hours) when once charged. The cost is 175s. (Berlin), fitted with two oxygen bottles.

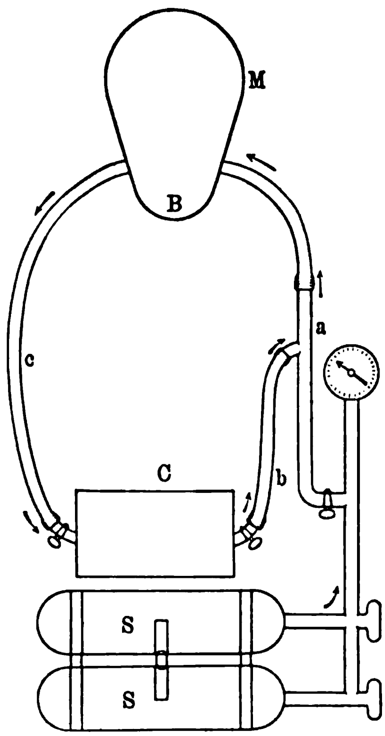

FIG. 15*b*.

55. In Austria two useful and not too expensive systems of portable oxygen apparatus for rescue work have been introduced of late, and have already been largely tested. These are—the Walcher-Gaertner pneumatophor, made and sold by Waldeck, Wagner & Benda, of Vienna; and the apparatus made by Neupert's Nachfolger, also of Vienna, after the designs of J. Mayer and Pilar.

The original pattern of pneumatophor consists of a flat, rectangular bag, carried on the chest, and measuring 22 inches in length and 18 inches in width. This bag (A, Fig. 15) is of close rubber, and contains

a steel bottle S_2 (charged with compressed oxygen), and a second bottle L, the latter being of glass, charged with a 40 per cent. solution of caustic soda for the absorption of the exhaled carbon dioxide, and surrounded by a perforated jacket of sheet-metal. From the bag A a 30-millimetre (1¼ inch) valveless pipe R leads direct to the wearer's mouth, and is held fast between the lips by the mouthpiece M. The nose is closed by a clamp N; whilst in an atmosphere charged with pungent gases the eyes must be protected by goggles. In breathing with this apparatus the wearer admits oxygen from the steel bottle S_2 into the bag A, as required, by means of the valve and hand-wheel *r*, the soda flask having first been broken by the pressure of a screw *s*, so that the lye can saturate the woollen lining of the bag A, and thus be in a position to absorb the exhaled carbon dioxide. As the soda solution tends to run down and accumulate at the bottom of the bag A, the latter must be reversed and shaken up from time to time to redistribute the liquid on the lining. In this operation care is, however, necessary to see that the bag does not get into such a position that the soda runs out into the mouthpiece, otherwise the caustic action of the lye would be attended with very disagreeable results. The original model having been found burdened with certain other defects, apart from the absence of a protective mask, it was modified and improved by Behrens for use at the Hibernia Colliery, (Westphalia).

In the new apparatus (Figs. 16, 17, and 18) the rectangular bag has been retained, but the alkali flask is no longer used, the liquid being poured direct into the bag A. Furthermore, the woollen lining of the latter has been replaced by a pad of loofah fibre to absorb the alkali; and, in order to ensure a better distribution of the weight, the oxygen bottle—or, rather, two bottles each containing 0·6 litre, and fitted with a valve—is carried in a bag resembling a cartridge pouch (Fig. 17). The oxygen is compressed to 100 atmospheres, and the bottles are connected with the bag A by means of a tube passing over the shoulder. Since the average consumption of the oxygen is at the rate of 1 litre per minute, the supply is sufficient for a couple of hours. The total weight of the apparatus, filled and ready for use, is 19½ pounds.

The tests made with this improved model at the Hibernia Colliery show that it is suitable not only for rescuing miners from remote parts of the workings in an atmosphere of irrespirable gases, but also for use in prolonged dangerous work in the pit, such as erecting, opening, and closing fire dams, putting up timbers, etc. in spaces filled with carbon monoxide.

Behrens gives the following particulars respecting the prime cost and

yearly upkeep (including instruction to the miners) of ten sets of the improved apparatus, each with two oxygen bottles:—

I. Prime cost—

1. One Stohmann charging apparatus for oxygen .	137	shillings.
2. Five steel cylinders, of 10 litres capacity, at 45s. .	225	"
3. Ten sets of respiration apparatus, at 127s. 6d. .	1275	"
4. Keys, carriage, etc.	63	"
Total . .	1700	"

or 170s. a piece.

II. Expense of upkeep, when ten men are exercised with the apparatus eight times a year—

(*a*) Cost of charging with caustic soda, 0·39s. a time .	31·2	shillings.
" oxygen, 12 litres per time and man, at 1·72s.	137·6	"
(*b*) Men's wages, 0·75s. per hour = 2·25s. per three hours	180·0	"
Total . .	348·8	"

or 34·88s. per set per annum.

As a rule, each rescue-party includes four men well skilled in the use of the apparatus; and in large pits ten sets of apparatus should be kept in good order, charged with the necessary oxygen, ready for emergencies.

Compressed oxygen can be obtained in commerce. It is, however, better to send the small bottles to be filled at the works than to charge them from storage cylinders at the pit, since, in the latter event, it is apparently impossible to obtain the necessary pressure of 100 atmospheres, even when an apparatus of the Stohmann type is used, unless the pressure in the storage cylinders is higher than the figure quoted above.

The O. Neupert's Nachfolger Respiration Apparatus.

56. This useful apparatus, shown in Figs. 19, 19*a*, 19*b*, 19*c*, and 20, consists of a bag AA (Fig. 19*b*), which is divided in the middle and is worn on the shoulders like a fur collar, the smoke helmet H, with the face mask M, being fitted over the open space. The mask is provided with a hollow rubber ring W, which fits tightly against the face when strapped on by means of the head and neck straps RR′, thus preventing any access of outside air to the face as soon as the pane of glass in front is closed. This window is protected from breakage by iron arches, and can be cleaned from deposited moisture by a wiper actuated from the outside. When the mask has been strapped on, the smoke helmet is placed over the head, one part of the bag AA fitting on the chest and

the other on the wearer's back. The oxygen necessary for breathing is contained in a steel bottle B (Fig. 19*a*), which is carried in a pouch on the left side, suspended from a strap. The bottle is connected with the air bag by a flexible tube, usually attached to the latter. When the apparatus is in position this tube is attached by a screw connection to the oxygen bottle, whereupon oxygen can be admitted to A by easing the valve as required. From A the air is drawn into the lungs through two metal tubes, *a* and *b*, connecting the bag with the space between the mask and the face.

The tubes *a* and *b* are fitted with valves of mica (Fig. 20), opening in opposite directions, in order to regulate inhalation and expiration and control the admission of oxygen to the nose and mouth of the wearer. At the same time, these valves prevent the immediate return of the expelled carbon dioxide to the lungs.

The steel bottle usually holds 1½ litres of oxygen, compressed to 100 atmospheres, though bottles holding 1 or 2 litres can also be used. When empty, the bottles can be easily disconnected and replaced by full ones during use in irrespirable gases, the tube being kept closed by the finger until attached to the fresh bottle.

In this case, unlike the Walcher-Gaertner apparatus, the exhaled carbon dioxide is absorbed, not by liquid caustic soda, but by solid sticks of caustic potash, introduced into the bag A through an aperture closed by a simple clamp. The caustic potash also absorbs the exhaled water vapour, and entirely prevents facial perspiration—a great advantage. The bag may also be emptied and cleaned through the aperture mentioned above.

A man consumes, when at rest,	20·8 litres or	29·5 grms.	of oxygen	per hour.
,, ,, at work,	27·9 ,,	39·8	,,	,,
And produces, when at rest, .	19·4 litres of CO_2 or	38·0	,,	,,
,, ,, at work, .	27·2 ,, ,,	53·5	,,	,,

Consequently the maximum hourly consumption of KHO would be 136 grammes. The Neupert apparatus, however, is charged with 500 grammes of KHO, or more than sufficient for two hours' use.

The store of oxygen in a 1½ litre bottle is about 2½ times the quantity theoretically required; but since there is always a loss of oxygen through leakage, and a certain excess of pressure must be constantly maintained within the mask, the supply of oxygen only lasts two hours.

The weight of the apparatus when fully charged is 15½ lbs.

As a rule, four men are associated with each rescue-party, the fourth carrying a couple of full oxygen bottles to act as reserve store, and also

for use in resuscitating any sufferers discovered in an unconscious condition.

The complete set of apparatus costs, with one oxygen bottle, 140s. ex-makers' works, Vienna, ten sets being supplied for 1225s. The compressed oxygen costs about ⅛d. to ½d. per litre.

According to experiments carried out by Dr. Heller, the wearers of the Walcher-Gaertner apparatus suffer considerably from perspiration during prolonged use; furthermore, the percentage of CO_2 in the air bag increased from 3·2 per cent. to 8·2 per cent., and a considerable acceleration in the number of pulsations and respirations was recorded. On the other hand, with the Neupert apparatus these inconveniences were not apparent, and the wearer experienced no oppression. These oxygen apparatus, however, still suffer from one defect, namely, that the supply of oxygen must be adjusted by the wearer. Now, as a rule, in consequence of insufficient experience, far too much oxygen is admitted to the air bag, the result being an excess of pressure, which retards exhalation and is thereby injurious. For this reason, frequent exercise with the apparatus is indispensable in order to prevent waste of oxygen in time of need, and thus uselessly shorten the length of time the apparatus can be used, and even perhaps cause the wearer to run into danger through remaining too long in the irrespirable atmosphere.

Recently the makers of this apparatus have introduced a machine for filling the oxygen bottles from the large (10-litre) gas cylinders. This pump costs £40, can be worked by two men, and will charge the bottles up to a pressure of 100 atmospheres in a short time.

The Contamination of Pit Air from other Causes than Injurious Gases.

57. It will be apparent from what has already been stated that the gases escaping from the rock at ordinary temperature, liberated from the coal at higher temperature, or disengaged by shot firing, and capable of dangerously contaminating the air of the pit, are few in number.

Many pits are almost or entirely free from such gases. Nevertheless, other causes of air contamination, which in time may injure the health of the miners, are present in all pits. These causes are partly physical partly mechanical in character, the former including excessively high temperature and moisture in the pit air, whilst the second category comprises the dust from rock and coal, and lamp smoke. An excessive draught is also injurious to the health of the men.

It is certain that in fiery pits, where there is urgent necessity for

driving out the pit gases by a strong ventilating current, the air is generally far better and purer than in pits where firedamp is absent and where ventilation is often neglected, the health of the miners suffering in consequence, as may be seen by a single glance at the appearance of the older men. These show the characteristic signs of deep suffering, namely, anæmia and bronchial emphysis, the face being pale, somewhat bluish and wrinkled, and the neck stooping forward when in motion: at the least strain the men become exhausted and prematurely invalid.

Such contaminations of the air must be regarded as equally dangerous with explosive gases; and here also the ventilating current should be powerful and well distributed in the workings, in order to keep the latter in a healthy condition.

Accessions of Temperature in the Pit.

58. The temperature of pit air is an important matter, both as concerns the health and working efficiency of the men. Miners who labour in hot atmospheres exhibit oppression, stagnated circulation in consequence of excessive perspiration, and short, quick breathing. Their capacity for work diminishes as the heat increases; and pit temperatures of 27° to 30° C. are quite unbearable.

One of the prime causes of heated pit air is the depth of the workings below ground. It is well known that, up to a depth of 20 to 25 yards from the surface, the rock temperature is invariable all the year round, and corresponds to the mean annual temperature of the locality (10° to 12° C.). Lower down, the temperature rises in proportion to the depth, the average rate being 1° C. for every 35 to 40 yards. The figures are not the same everywhere, but fluctuate a little in accordance with the geognostic character of the rock. At some places, again, high temperatures obtain close to the surface—for instance, where hot springs ascend from the depths and warm the surrounding rock, or where volcanic activity has not yet entirely become extinct. Thus at Teplitz (Bohemia) the sinking of shafts at the springs had to be quickly abandoned, owing to the high rock temperature, and recourse had to deep boring, when the thermal springs had to be deepened in consequence of the loss by drainage into adjacent pit workings. The air in coal pits is almost invariably warmer than the adjacent rock, owing to the liberation of heat by the oxidation of the exposed coal. Heat is also generated by the presence of men and animals, burning lights, shot firing, decaying wood, etc. However, by passing a continuous air current of sufficient strength through the pit, the temperature of the surrounding rock is

gradually reduced, and as the other sources of heat lose their action the air is brought into a bearable condition.

Moisture in Pit Air.

59. Owing to the previously mentioned faculty of air to greedily absorb moisture, and since water usually exudes from the gallery walls, pit air is generally saturated with water vapour. Now, very damp air is just as bad for the human organism as very dry, since it retards evaporation from the skin and diminishes the amount of oxygen inhaled. On strong constitutions, however, the moisture in pit air has but very little effect.

Mechanical Causes of Contamination in Pit Air.

59*a*. In dry pits the working operations result in the production of rock dust and coal dust, which spread through and are deposited in all parts; hence the stronger the air current the farther is the dust carried. Now, as already stated, the only way to nullify the dangerous tendencies of coal dust is by a thorough wetting. This is an instance where it is necessary to choose the lesser of two evils.

Certain kinds of metallic dust, such as that from arsenic, cinnabar, copper, lead ores, etc., are also injurious to respiration.

Lamp smoke is most frequently generated in lamps fed with colza oil, and is very troublesome to the lungs; tallow gives less smoke than colza oil; and it has already been mentioned that benzine safety lamps are free from smoke or fumes, on which account alone they would be preferable to colza oil lamps. Excessive draughts, especially in narrow headings, are a frequent cause of colds in miners, and therefore it is necessary, from hygienic considerations, to avoid a higher velocity than 5 to 6 yards per second for the air currents Other reasons favour the same course; but this is a matter that will be discussed later on.

CHAPTER III.

CALCULATING THE VOLUME OF VENTILATING CURRENT NECESSARY TO FREE PIT AIR FROM CONTAMINATION.

60. Replenishing Pit Air by Fresh Air from Aboveground.

It is evident from the foregoing that pit air gets foul in a very short time, and to remedy this state of things the air must be continually renewed—an object effected by forcing through the underground workings a current of fresh air, which takes up the injurious gases and carries them away uninterruptedly. The question then arises as to how much fresh air must be passed through the pit in a given time, in any particular instance, in order to keep the atmosphere in a fit state for respiration, preserve the health of the miners, and prevent the occurrence of firedamp explosions. Some of the factors influencing this calculation are: the number of men and animals employed, but more particularly the volume, admittedly great, of noxious gases liberated by the decomposition of the blasting explosives used; then the extent of the workings or the quantity of the diurnal output of minerals therefrom; and, finally, the presence or absence of firedamp—since, as we have seen, the only means for obviating the dangers from firedamp is by sufficiently diluting the pit gas with air and then carrying it away out of the mine.

Again, it has already been mentioned that pit air can be contaminated either by the abstraction and consumption of the contained oxygen, or by the admixture of irrespirable gases. As the following calculation will show, the former of these causes is of comparatively minor importance, whether in the air of ore mines, safe coal mines, or fiery pits.

A man at rest consumes 20·8 litres of oxygen per hour and 27·2 litres when at work, *i.e.* a mean consumption of 24·35 litres. Now, pure air contains about 21 per cent. by volume of oxygen and 79 per cent. of hydrogen, so that if we assume—as may safely be done in view of what has been stated above with regard to oxygen—that 2 per cent. of the atmospheric oxygen can be abstracted during respiration, without

injury to health, then the requirement x of the human organism in respect of air will amount to $24{\cdot}35 = \frac{x \,.\, 2}{100}$, or $x = 1{\cdot}218$ cubic metres (43 cubic feet).

Allowing an equal quantity for the miner's lamp, then one man with a lamp will consume 2·436 cubic metres (86 cubic feet) of air per hour.

Moreover, if we accept Dr. Schondorf's assumption that the oxygen so consumed hourly by a man and lamp is only one-seventeenth of the total oxygen consumption in the pit, then each man would require $17 + 2{\cdot}436 = 41{\cdot}412$ cubic metres (1460 cubic feet) per hour, or 0·7 cubic metre (24½ cubic feet) per minute. This, however, is far from sufficient, especially when a deal of shot firing is in progress.

According to Demanet, the following gases are liberated by the explosion of blasting powder:—

CO_2	32·13 per cent.
CO	33·75 „
N	19·03 „
H_2S	7·10 „
H	5·24 „
CH_4	2·75 „
	100·00 „

The whole of these gases are irrespirable, and 40·85 per cent. of them are even highly dangerous.

Theoretically, 1 gramme of powder liberates 331 cubic centimetres of gas at 0° C. Consequently 1 kilogramme of powder liberates, on explosive decomposition, 3·31 cubic metres of gas, which at 20° C. occupies a space of $3{\cdot}31\ (1 + 20 \times 0{\cdot}003665) = 3{\cdot}35$ cubic metres.

Thus if one kilogramme of powder be consumed per minute in the pit, and furnish 3·35 cubic metres of injurious gas, then, assuming that the outflowing air may contain 0·06 per cent. of such gas without injury, the volume of pure air introduced into the mine per minute must be $1667 \times 3{\cdot}35 = 5584{\cdot}5$ cubic metres, or 93 cubic metres per second.

According to a report by Mining Inspector Nimptsch, the amount of blasting material consumed at the Deutschland pit, Schwientochlowitz, near Koenigshuette, Upper Silesia, per eight hours' shift, is: 342 kilogrammes (powder, 328 kilogrammes; dynamite, 13·5 kilogrammes, and 118 rings of fuse), or 0·7 kilogramme per minute. The amount of gas thereby liberated, on the basis of 3·35 cubic metres per kilogramme at 20° C., would therefore be 2·345 cubic metres; and therefore, to ensure reduction of the gas content to 0·06 per cent., or 1667-fold dilution, the volume of air necessary per minute would be $2{\cdot}345 \times 1667 = 3909$ cubic

metres, or 65 cubic metres per second. As a matter of fact, however, the air supply in this pit is only 3200 cubic metres per minute, or 53⅓ metres per second.

Such an amount of ventilation just about reaches the necessary limit, without, however, enabling one to say that the condition of the air is very good.

Since the amount of coal raised at the pit in question is 2360 tons per shift of 680 men, the volume of air supplied per ton of coal raised is 1·35 cubic metres, or 4·7 cubic metre per man.

In the construction work of the Mont Cenis Tunnel it was found that the amount of fresh air required was 10 cubic metres per man and 7 cubic metres per lamp an hour, and 250 cubic metres for removing the gas liberated by each 1 kilogramme of explosive in blasting. Now, these quantities are evidently insufficient, it being well known that the whole of the working staff in the Mont Cenis Tunnel is affected with tunnel sickness; and though this complaint is immediately caused by an intestinal worm (*Anchylostomum duodenale*), yet the circumstance that this worm is able to thrive in the viscera of the workmen must be mainly attributed to imperfect ventilation.

Experiments on the amount of air necessary in the pit have also been carried out in Westphalia, with the following results:—

Air required per hectare (2½ acres) of pit area .	6·120 cubic metres.
" " ton of coal raised . .	1·034 "
" " man at work . . .	1·712 "

per minute.

These figures seem rather low, but apply solely to the actual working places.

It is highly desirable that further observations should be made and published with reference to the amount of explosives consumed in non-fiery mines, the resulting volume of irrespirable gases, and the condition of the effluent pit air, the state of our knowledge in this respect being still very imperfect.

Fiery mines naturally require a larger volume of air in order to reduce the percentage of firedamp in the effluent air to 0·5–0·6 per cent., or 1 per cent. at the maximum, always premising that any dangerous coal dust must have first been thoroughly sprinkled in the manner already described.

In reality, a larger proportion of methane is often found in the up-cast air current. Thus Dr. Haldane gives the following figures at several English collieries:—Podmore Hall, 1·1 per cent.; Talk o' th' Hill, West

Bullhurst, 0·88 per cent.; Tylorstown, 1·87 per cent. The last-named figure is indeed far too high, and indicates imminent risk of a firedamp explosion in the event of any check in the ventilation. For the same reason, all fiery pits are compelled to have a large reserve of ventilating machinery so as to be able to increase the current in the event of an emergency, such as a local ignition of firedamp, a sudden inrush of gas, etc., and thus restore the pit to its normal condition in the shortest possible time.

General Remarks on the Flow of Gases.

61. In order to deal with the flow of gases and gaseous mixtures arithmetically, it is necessary to first know their density; and this property is influenced by the chemical composition, warmth, atmospheric pressure, and the percentage of moisture present. As a rule, the chemical examination can be dispensed with in the case of air, since any other than the ordinary gases present will usually be so in such minute proportion as to leave the specific gravity practically unaffected.

Temperature is measured with the mercury thermometer, in using which the following precautions should be borne in mind:—

(1) When the bulb of the thermometer has become covered with drops of moisture, these should be carefully wiped off before taking the reading, otherwise the water in evaporating will lower the temperature.

(2) The reading must be commenced after a short rest, and then repeated several times, since individual gusts of air may give a temperature that is not the true mean.

(3) The readings must be repeated, because the temperature of the pit may momentarily alter. For reading off temperatures in the shaft, the latter is divided into three equal sections or levels, the mean temperature is ascertained in each, and from these results the density of the whole column of air is deduced. Occasionally the temperature of the surrounding rock will have to be determined as well. With this object, a hole is drilled not less than 1 foot deep into the rock, an interval of one quarter-hour being then allowed to elapse before inserting the thermometer: this is because the sides of the hole may have become somewhat heated in drilling. When the thermometer is in position the hole is plastered up with clay, and the temperature is read off after a short interval.

62. Atmospheric Pressure.—This pressure is measured with the barometer, and all readings that are taken at any other temperature than zero Centigrade must be calculated to that standard.

The formula for pressure is $P = h \times p$ (height × weight) kilogrammes, and it is on this principle that the mercury barometer and the pressure gauge (manometer) have been constructed. The mercury barometer records the pressure of the atmospheric column. In this case $P = h \times 13598$ kilogrammes, the last figure indicating the density or weight of a cubic metre of mercury at 0° C. Under the influence of heat this metal expands $\frac{1}{5550}$ of its volume for each 1° C. traversed. Therefore, by including the factor of temperature, the above pressure formula will assume the following form:—$P = h \times 13598 \times \frac{5550}{5550 + t^\circ}$, wherein t° expresses the temperature in degrees C.

Assuming the height of the mercury column to be $h = 0{\cdot}75$ metre and the temperature $t^\circ = 0^\circ$, then $P = 10198{\cdot}5$ kilogrammes per square metre. When $t^\circ = 16^\circ$ C., $P = 10161{\cdot}7$.

Hence temperature cannot be neglected in barometric readings. Aneroid barometers are not instruments of precision, and therefore cannot give accurate readings.

63. The object of the manometer or pressure gauge is to record the difference of pressure of two media or in two separate spaces.

The simplest form, and the one mostly used for measuring the pressure of air in mines, is the water gauge (Fig. 21). This consists of a bent glass tube with two limbs a and b, the bent end of b projecting through a partition separating the chamber M from M′, the former of which exhibits a higher atmospheric pressure than the latter. The bent portion of the tube is filled with water. The difference between the pressures obtaining in M and M′ is recorded by the difference h in the water level in a and b, measured in millimetres on the graduated scale. When, as is customary, distilled water is employed, $P = h \times 1000$; and for $h = 1$ millimetre, $P = 0{\cdot}001 \times 1000 = 1$ kilogramme. Consequently every millimetre difference between the two water levels corresponds to 1 kilogramme extra pressure per 1 square metre. True, water expands slightly when heated ($\frac{1}{3200}$ per 1° C.); but this slight error can be generally neglected. It is necessary to have gauge tubes of somewhat large diameter, in order to counteract the meniscus forming at the planes of contact with the water.

64. The De Vaux Pressure Gauge (Fig. 22) consists of a cylindrical vessel A, partly filled with water and provided with a central cylindrical orifice B, the walls of which do not reach quite to the bottom of A. A float f rests on the water surface O O, and is balanced by a weight q. The fluctuations in the water level are communicated to the indicator x by means of a cord attached to the float f, and passing

round a pulley n. Communication with the outer air and the interior of the vessel A is established by turning a tap r, whilst a tap r' enables the space C to be put in communication with M, the pressure wherein is to be measured.

The instrument is so arranged that a slight fluctuation of the water level causes a wide sweep of the indicator x. Though the cord passing over the pulley n, and actuating the indicator x, may slip over the said pulley, it is nevertheless easy to test the instrument by the aid of the taps r and r', and set the instrument to the zero point on the scale.

65. Fluctuations of Pressure in Pressure Gauges.

These pressure gauges are attended with the defect that the surface of the water is subject to continual fluctuation while the measurements are being taken, the consequences of this irregularity being more particularly noticeable in the case of ventilating fans that exhibit variable efficiency, in which cases it is difficult to obtain accurate measurements. As a rule, in such event the mean of the maximum and lowest readings is taken $\left(\frac{M+m}{2}\right)$. Occasionally, however, this furnishes inaccurate results; and therefore, in order that the reading shall correspond exactly with the truth, the time factor of the highest and lowest readings must be taken into consideration. The fluctuations in the water level are due to the momentary displacement of the mass of water by the variable pressure to which it is exposed. To make allowance for the time factor, it is sufficient to interpose a resistance in the tube connecting the two limbs of the gauge. This can be done by constricting the connecting tube (Fig. 23), or by dropping some shot into the bottom of same. Nevertheless, these artifices are not entirely reliable, since the connecting tube may thereby become choked up completely.

66. The Guibal Pressure Gauge (Fig. 24).

This instrument contains two wide glass tubes A and B, which are provided with metal covers and tubular connections, and are joined together below by a narrow tube, fitted with a tap r, that can be opened or closed to any desired extent. The tube A is opened at the top, and is in direct communication with the outer air, whilst B is connected by means of a rubber tube with the space wherein obtains the pressure to be measured. Between the two is mounted a vertically adjustable scale. The rapid fluctuation of level in the tubes can be retarded by adjusting the tap r.

67. The Maess Vacuum Meter with Floating Scale (Fig. 25).

This instrument, the invention of W. Maess, of Dortmund, consists of a glass *a*, of oval cross section, containing water in which floats the scale *b*. At the upper end this vessel is connected by a tube *e* with the space to be tested for the degree of attenuation (vacuum) of the contained air, etc. At the same time *a* is connected at the bottom with a narrow tube *c*, the water level in which recedes in proportion as the pressure above the surface of the water in A is reduced. The instrument is attached to a board *d*, for convenience in hanging up. No fresh water need be poured into the wide vessel *a* until the loss by evaporation is such that the float of the scale touches bottom.

67*a*. Multiplication Pressure Gauge (Fig. 26).

When great accuracy is required with tubular gauges, use is made of the so-called multiplication pressure gauge (Fig. 26), wherein the two parallel tubes are set on a slope. The most suitable gradient is 1 : 5, in which case the length measured on the slope will be five times the vertical length. The two limbs, which are connected below, terminate at the upper portion in vertical ends, to which are attached the rubber tubes connecting the instrument with the space under examination. For measuring pressures this space is placed in communication with the upper limb of the gauge, whilst for vacuum measurements the lower limb is used.

The gauge glass and scale are mounted on a vertical board, which is attached to a horizontal board fitted with set screws to ensure perfect levelling.

68. A very useful pressure gauge, which automatically records the pressure for twenty-four hours at a time, on a strip of paper mounted on a drum, and also marks the hours thereon, is that of Ochwaldt (Koehler).

Points to be Noted when Working with the Pressure Gauge.

69. In using the pressure gauge, attention should be bestowed on the following points:—First is the method of placing the instrument in connection with the space or chamber under examination. If the air in this space were stationary, the pressure could be measured without difficulty. As a rule, however, such is not the case, the air being generally in motion. According to the law of hydraulics, the pressure exerted by a fluid in motion on the walls of the conduit

through which it flows is diminished by that portion of the pressure by which the effluent velocity is produced.

Now, there are three ways of passing the gauge tubes through the wall of the air conduit (see Fig. 27). In the first position the bent end of the tube is parallel to the direction of the air current, and turned in the opposite direction thereto. Assume the air velocity to be v. When $P =$ the pressure indicated by the gauge, and h the total pressure inherent in the air current, then $P = h$.

If, as in No. 2, the air passes by the straight extremity of the gauge tube, then $P = h - \frac{v^2}{2g}$. Consequently, in order to keep h right, $\frac{v^2}{2g}$ must be added to the pressure P. $\left(h = P + \frac{v^2}{2g}\right)$.

Thirdly, if the bent end of the tube, though parallel with the air current, be turned in the same direction as the flow, then we have $P = h - \frac{2v^2}{2g} = h - \frac{v^2}{g}$.

It is always advisable to make use of the position No. 1.

If the opening in the wall of the air way be too large for the gauge tube, the free space must be well plastered up with clay, tallow, or the like.

MOISTURE CONTENT IN PIT AIR, AND SPECIFIC GRAVITY DETERMINATIONS.

70. When pure water is allowed to evaporate in air, it is gradually and completely converted into water vapour. On the other hand, when a certain quantity of water is placed in an enclosed space, *e.g.* under a bell glass, only a portion will evaporate in any case, owing to the fact that the space cannot absorb more than a definite quantity of water vapour —constant with the temperature—which is then termed the saturation limit of this space at the prevailing temperature. This limit rises with the temperature: if that increases, then a larger amount of the water evaporates; if, on the other hand, the temperature falls, a portion of the water vapour will be deposited in the form of water drops on the walls of the glass.

Dalton, in 1801, found that the capacity of a space for absorbing the vapour of any liquid is independent of the presence of any other gases in this space, and that consequently a space measuring, for example, 1 cubic metre will at any given temperature always absorb the same amount of water vapour, immaterial whether the same be devoid of air or filled with atmospheric air, oxygen, hydrogen, or any other gas.

On account of its elasticity, the vapour confined in any space exerts

a certain pressure on the surrounding walls of the vessel, etc. This pressure, or the tension of the gas, increases with the temperature, as also with the amount of water itself. Each temperature therefore corresponds with a certain limit of saturation and a given tension. Consequently, in calculating the weight of a volume of air containing water vapour, the tension of the latter may be taken as a basis instead of the amount of water, since it follows, from Mariotte's law, that at a given temperature and given volume the weight of the water vapour, even below the saturation limit, increases like the tension.

If f be taken to represent the tension of the water vapour in the imperfectly saturated air, and F the tension in saturated air at the same temperature, we then have $\frac{n}{100} = \frac{f}{F}$ and $f \; \frac{nF}{100}$.

The tension of water vapour at any given temperature can be found in the table already given (p. 18), or may be calculated by means of the Magnus formula, *i.e.* $F = a \times \beta^{\frac{t^\circ}{\gamma + t^\circ}}$, wherein F represents the tension of water vapour at saturation point (air), t° the temperature in degrees C., $a = 4{\cdot}525$, $\beta = 10^{7 \cdot 4475}$, and $\gamma = 234{\cdot}69$.

Thus if $t^\circ = 9{\cdot}2^\circ$ C., F then $= 4{\cdot}525 \times 10^{7 \cdot 4475 \times \frac{9 \cdot 2}{234 \cdot 69 + 9 \cdot 2}}$, or $= 8{\cdot}64$. (According to the table, $F = 8{\cdot}69$.)

The weight P of 1 cubic metre of pit air is equal to the sum of the weight of 1 cubic metre of pure dry air and 1 cubic metre of water vapour at t, and with the tension f. We thus have $P = 1{\cdot}29344 \, \frac{B - f}{0 \cdot 76} \times \frac{1}{1 + at^\circ}$.

Here B refers to the height of the barometer at the site of the observation, t° the air temperature, a the coefficient of expansion of gases $= 0{\cdot}003665$, and $1{\cdot}29344$ is the weight of 1 cubic metre of dry air at 0° C. and 760 millimetres barometric pressure. Since the weight of water vapour is only $\frac{5}{8}$ that of dry air, the weight of 1 cubic metre of water vapour P_1, at the temperature t° and the tension f, is—

$$P_1 = \tfrac{5}{8} \times 1{\cdot}29344 \, \frac{f}{0 \cdot 760} \times \frac{1}{1 + at^\circ}.$$

The weight of the mixture P_2 is therefore—

$$P_2 = P + P_1 = 1{\cdot}29344 \, \frac{B - f}{0 \cdot 76} \times \frac{1}{1 + at^\circ} + \frac{\frac{5}{8} \times 1{\cdot}29344 \, \frac{1}{1 + at^\circ} f}{0 \cdot 76}.$$

$$P_2 = \frac{1{\cdot}29344}{1 + at^\circ} \left(\frac{B - f}{0 \cdot 760} + \frac{\frac{5}{8} f}{0 \cdot 760} \right) = \frac{1{\cdot}29344}{1 + at^\circ} : \frac{B - \frac{3}{8} f}{0 \cdot 760}.$$

On replacing f by its value $\frac{nF}{100}$, we have—

$$P_2 = \frac{1{\cdot}29344}{1+at^\circ} \times \frac{B - \frac{3}{8}\frac{n}{100}F}{0{\cdot}760} \text{ kilogrammes.}$$

If, in addition to water vapour, the pit air also contains other gases, the value 1·29344 will have to be replaced by the weight p_0 of the dry gaseous mixture. In such case p_0 is equal to a per cent. air $+ b$ per cent. $H + c$ per cent. $N + d$ per cent. $O + e$ per cent. $CH_4 + f$ per cent. CO $+ g$ per cent. CO_2.

On posing $a+b+c+d+e+f+g=1$, we obtain—

$$p_0 = 1 \times a + b \times 0{\cdot}0896 + c \times 1{\cdot}2553 + d \times 1{\cdot}430 + e \times 0{\cdot}7218 + f \times 1{\cdot}252 + g \times 1{\cdot}9714.$$

71. Example I.—

Assume the gaseous mixture to have the following composition—

		Weight of 1 cubic metre at 1° C. and 760 millimetres.
Air	= 0·90	= 1·29344 kilogrammes.
Firedamp	= 0·09	= 0·7218 „
CO_2	= 0·01	= 1·9714 „
	1·00	

The first thing is to determine the weight of this mixture at 0° C. and 760 millimetres. In this case $p_0 = 0{\cdot}90 \times 1{\cdot}29344 + 0{\cdot}09 \times 0{\cdot}7218 + 0{\cdot}01 \times 1{\cdot}9714 = 1{\cdot}248772$ kilogrammes.

If now we have to ascertain the weight P_3 of the mixture when the local barometric pressure is $B = 0{\cdot}755$ metre, the temperature $t = 16°$ C., and the saturation ratio $\frac{n}{100} = \frac{4}{5}$, then, according to the table on p. 18, $F = 0{\cdot}013536$. Consequently $P_3 = \frac{p_0 (B-f)}{0{\cdot}76\ (1+at)}$.

Furthermore, the weight of 1 cubic metre of water vapour is—

$$P_1 = \frac{\frac{5}{8} \times 1{\cdot}29344 f}{0{\cdot}76\ (1+at)},$$

and the weight of the mixture $P_4 = P_3 + P_1$; therefore—

$$P_4 = \frac{p_0 (B-f)}{0{\cdot}76\ (1+at)} + \frac{\frac{5}{8} \times 1{\cdot}29344 f}{0{\cdot}76\ (1+at)}.$$

Now, since $f = \frac{4}{5}$ F, and F at 16° C. $= 0{\cdot}0135636$, we have—

$$P_4 = \frac{p_0 (B - \frac{4}{5} \times 0{\cdot}0135636) + \frac{5}{8} \times 1{\cdot}29344 \times \frac{4}{5} \times 0{\cdot}0135636}{0{\cdot}76\ (1+at)}$$

On substituting the values, we obtain—

$$P_5 = \frac{1}{0{\cdot}76\ (1 + 16 \times 0{\cdot}003665)} [1{\cdot}248772\ (0{\cdot}755 \times 0{\cdot}8 \times 0{\cdot}0135636)$$
$$+ 0{\cdot}5 \times 1{\cdot}29344 \times 0{\cdot}013636], \text{ i.e.} = 1{\cdot}1671 \text{ kilogrammes.}$$

Since the weight of pit air mainly depends on the atmospheric pressure, temperature, and degree of saturation, these factors alone are generally taken into calculation. In such event the formula for the weight of 1 cubic metre is—

$$P_2 = \frac{1{\cdot}29344 \times (B - \frac{3}{8} \frac{n}{100} F)}{0{\cdot}76\ (1 + at)} \text{ kilogrammes.}$$

72. Example II.—

If the temperature of the pit air be $9{\cdot}2°$ C., $\frac{n}{100} = 0{\cdot}5$, and the local barometric pressure $B = 0{\cdot}7472$ metre, then—

$$P_2 = 1{\cdot}29344 \frac{0{\cdot}7472 - \frac{3}{16} \times 0{\cdot}00869}{0{\cdot}760\ (1 + 0{\cdot}003665 \times 9{\cdot}2)} \text{ kilogrammes.}$$
$$P_2 = 1{\cdot}227496 \text{ kilogrammes.}$$

MEASURING THE VENTILATING CURRENT.

73. Fundamental formula for measuring the ventilating current.

If Q be taken to express the volume of air passing through a heading per second, v the velocity of same per second, and S the sectional area of the heading, then $Q = S \times v$ cubic metres per second.

74. MEASURING THE VELOCITY OF THE VENTILATING CURRENT.

A. Measurement by the aid of readily transportable bodies.

B. Measurement of the air velocity at a given spot.

A. When the velocity of the ventilating current is to be measured by the aid of light substances, it is an essential preliminary that the sectional area of the heading to be measured must be of constant uniformity; in the alternative case, it is merely necessary to determine the sectional area at the spot where the measurements are made.

Measurement by the first method is rather unreliable when the heading in which the measurements are made is greater in some parts and smaller in others. Headings or cross drivages lined with masonry are best for this purpose. The operation is performed by determining with a seconds watch the time occupied by the ventilating current in

travelling a certain distance. If this distance be represented by W and the time by T, then the velocity $v = \frac{W}{T}$. If the volume W of the air is to be determined at the same time, the mean sectional area S of the gallery must be measured and calculated.

(1) *Measuring the Velocity of the Ventilating Current by the Aid of Light Substances.*

The substances chiefly employed for this purpose are down and downy feathers, which are readily transported by the current and are visible to the eye, the assumption being that these substances move at the same rate as the air itself. To perform the operation, two observers are stationed from 100 to 200 metres apart in the heading. They must be furnished with watches recording seconds, or else set up a standard second pendulum (length 0·9938 metre). The observer nearest the intake shaft throws a handful of down into the air, and calls to his companion, who then counts the seconds until the feathers reach his station. At first a few come in sight, then the bulk, and finally a few stragglers to finish off. This implies that the air waves in the heading are not all endowed with the same velocity; and in such event the mean of the readings given by the first and last feathers, *i.e.* the quickest and slowest air waves, is taken. However, as it is rather difficult to ascertain when the last feathers pass the observer, and as the first are always seen a little too late, the resulting value for the velocity is more likely to be below than above the truth.

(2) *The Powder Smoke Test.*

Somewhat similar results are obtained by burning a little gunpowder in the measuring section of the gallery. This method has the advantage that the powder smoke is both seen and smelt, and that it does not hang to the walls of the heading. The first observer may also fire a pistol (on giving the word "One, two, three") to produce the smoke. However, as the shot may easily cause a disturbance in the velocity of the air current, it should be fired transversely, and not along the heading in either direction.

(3) *The Ether Test.*

To measure the velocity of the air current by means of ether, the first observer is provided with a thin glass bottle filled with that liquid. At the word of command this bottle is smashed. As in the feathers

test, both observers must have come to a definite understanding over the moment of commencing the experiment. The test is not very accurate, owing to the difficulty of grasping the right moment that the light ethereal vapours arrive at the second station.

(4) *Measurements with the Open Miner's Lamp.*

A simple means of measuring currents of moderate velocity consists in carrying an open miner's lamp for a distance of 100 to 150 yards along a heading of large and uniform sectional area, the pace being so regulated that the lamp flame remains vertical throughout. In such case the bearer is evidently moving at the same speed as the air. In this case, also, the time must be measured with a seconds watch; the mean of three observations will give an approximately correct result. When it is merely a question of ascertaining, in slow currents, whether any flow of air is taking place at all, the best and simplest plan is by blowing a thick cloud of tobacco smoke into the air. For instance, when it is desired to find out whether a shaft is acting as an intake, it is easy to observe, with tobacco or cigar smoke, whether a cloud blown at the pit mouth is drawn down into the shaft or not.

75. *B.* Measuring the velocity of the air current in a given spot by the anemometer. The foregoing methods furnish results that have not much claim to accuracy. For this reason it is found preferable to perform the measurements at a given point in the mine, all that is further necessary being to determine the sectional area of the heading at that point. In these cases the instrument known as the anemometer is usually employed. Though greatly improved, so that their errors have been minimised and can readily be controlled, these instruments are not perfectly infallible, and therefore it is necessary to guard against the erroneous idea that absolutely accurate measurements are obtainable by their aid.

The anemometers used at first were similar to the instruments employed for measuring the flow of water in rivers—such, for example, as Pitot's tubes, the anemometers of Lind and Brunig, the pendulum anemometers of Devillez, Henault, and Dickinson, the vane anemometer of Combes and Biram. As all these instruments have gone out of use for pit work, and moreover are fully described in text-books on mining, they need not be dealt with any further here.

The newer types of vane anemometers of Neumann, Casella, Recke, and Maess are all based on the same principle as that of Combes and Biram, the air velocity being determined by the revolutions of a fan connected with a train of counting gear.

76. The Casella Anemometer (Fig. 28).

This instrument presents the advantage of enabling the velocity of the air current to be read off direct on the dial plate, thus saving the trouble of calculating by means of a formula. The eight vanes of the fan are made of aluminium, and are mounted at an angle of 30 degrees to the vertical plane, which is normal to the axis of the fan. The shaft is connected, by means of a worm screw, with the counting mechanism, which is mounted in a horizontal case. The pointers revolving on the dial plate indicate the number of revolutions made by the shaft, this figure being identical with the velocity of the air current in units of length (in this case metres) per second. All that is necessary before commencing the observation is to note down the index of the large pointer, and, in the case of prolonged observations, the position of the pointers recording hundreds, thousands, etc. To start the instrument, the stop-rod is released, this allowing the counting mechanism to come into action. At intervals of 60 seconds the counting mechanism is stopped by pressing the stop-rod, leaving the fan to run free. The index is finally read off, giving the number of revolutions made by the fan, each movement of the large pointer through one division on the dial plate corresponding to a distance of one metre traversed by the air current. To the resulting figure must be added a constant (usually ten per minute), to allow for the effects of friction; and by dividing the velocity per minute by sixty the value per second is obtained. When the instrument is in such a position that it cannot easily be reached by the hand, the stop-rod can be actuated by means of two cords. This is in so far an advantage, in that it obviates the necessity for the observer to obstruct the air way with his body and thereby retard the free passage of the current.

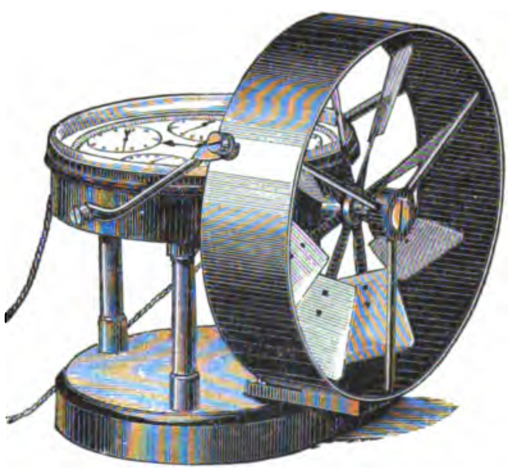

Fig. 28.

The anemometer can also be fitted with a sleeve for mounting on a rod; or, again, it can be attached to the board *c* of a telescopic stand (Figs. 29 and 29*a*), which can be fixed up in a heading by means of

spikes at the top and bottom. The board *e* is adjustable on the outer tube *a* of the stand, and is fixed in any position by a screw-clamp *i*.

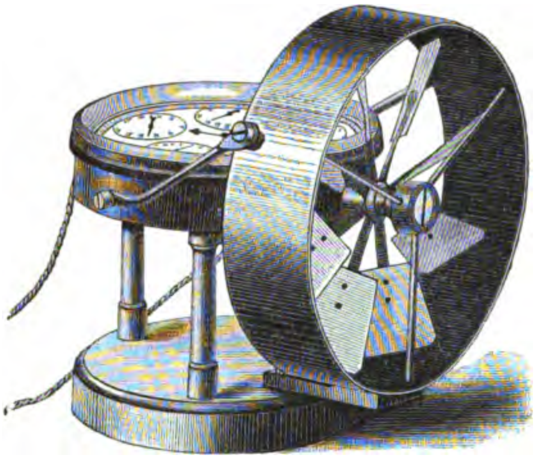

Fig. 30.

Fig. 31.

The iron rod *b* slides in and out of the tube *a*, according to the height of the gallery, and is also fixed in position by a clamp *k*. When fully extended, the stand measures about 8 feet in height. When several observations have to be made in the same heading at different levels in close proximity, the best thing to do is to drive a few props slantwise in the gallery, and hang the anemometer on these.

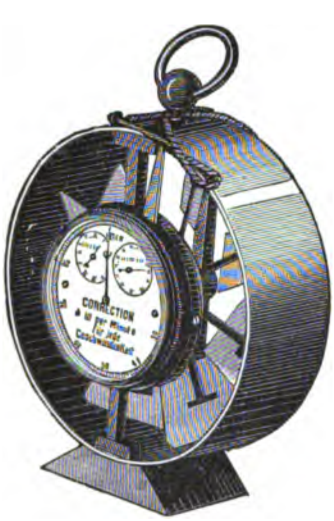

Fig. 32.

The Casella anemometer, shown in Fig. 28, is 75 shillings (W. Maess, Dortmund); the smaller models, shown in Figs. 30, 31, and 32, for smaller readings, up to 1000 metres and 100 metres respectively, costing 54 and 36 shillings.

The Maess Clockwork Anemometer (Fig. 33).

77. A clockwork anemometer for pit use has recently been introduced by W. Maess, of Dortmund. In this instrument a train of clockwork is connected with the counting mechanism in such a manner as to throw the latter into and out of gear, so that the instrument gives in each case the exact results of one minute's observation. The clockwork is wound up by means of the stem winder *a* (one winding being suffi-

cient for about twenty observations). Then the hand is set to zero point, by pressing a small knob *b* and turning the winder. The difference between the zero point on the dial and the large O for setting the hand, serves to replace in this instrument the correction usually made. Like other vane anemometers, the instrument is placed in position with the vanes facing the current, and the clockwork is started by pushing the projecting lever *c* towards the centre for a moment. After about three-quarters of a minute the clockwork sets the counting mechanism in action, and this latter runs for exactly a minute, to be then stopped by the clockwork again. The clockwork itself is also brought to a standstill, and the figures marked by the hand on the dial plate show the true velocity of the air current without any calculation being required.

FIG. 33.

78. THE ROBINSON CUP ANEMOMETER (Figs. 34*a* and 34*b*).

In fiery mines it is advisable to measure the velocity of the air current and the amount of air drawn through the pit, somewhere aboveground, say, in the manager's office, and so provide some check on the regularity of the ventilation. With this object a testing station is provided in the main air way, and the continuous anemometers therein situated are connected with an electric counting apparatus above bank. The best instrument of this type is the Robinson anemometer, improved by Dr. Schondorff. Four hemispherical cups *a*, mounted on a rectangular cross *b b*, are caused to revolve in the horizontal direction shown by the arrow (Fig. 34*b*), because the air pressure on the concave sides of the cups is greater than on the convex surface. The vertical shaft *c*, supporting the cross *b b*, carries at its upper end a worm *d*, which drives a small wheel *e*. As the wheel revolves, a pin *f* thereon presses on a spring *g*, which in turn acts on a second spring *g*, and thus completes an electrical circuit. The electric current is conveyed into the anemometer by means of two wires *h*, *h* and the clamping screws *n*, *n*. These wires are led up to bank, and there attached to a counting mechanism in a suitable position. When the contact of the two springs *g*, *g* closes the circuit, an armature aboveground is released, and thereby the counting

mechanism is enabled to move forward by one tooth. The velocity of the air current can be read off direct on the dial attached to the counting apparatus, or by means of tables provided for that purpose, or the same may be recorded graphically by a special appliance.

The mechanism in the underground station is protected by a glass cylinder *k*, which revolves with the arms *b b*, and dips into an oil bath *i* in the lower part of the frame, and thus prevents the incursion of dust and dirt.

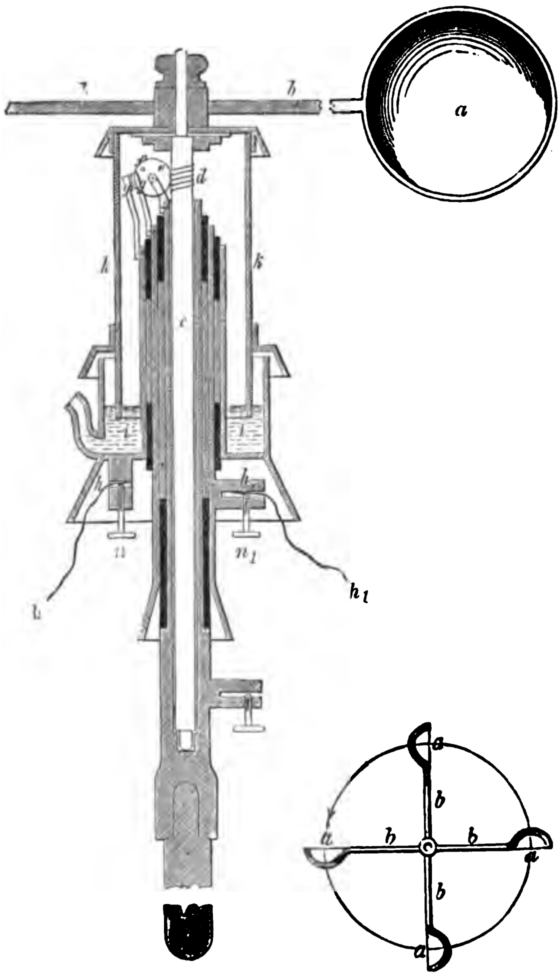

FIG. 34*a*. FIG. 34*b*.

As the cups of this apparatus rotate, a certain amount of air is carried round as well, and this must be taken into account in calculating the air velocity. According to Grashof, the air velocity $w = 3{\cdot}23v$: if v be taken to indicate the difference between the peripheral velocity, v_0 of the cup centre, and v_1 the velocity of the accompanying air, v_1 should be set down as equal to $0{\cdot}02377w$.

If, for instance, the peripheral velocity v_0 of the cup centre is found to be 2 metres per second, then—

$$w = 3{\cdot}23v, \text{ and } v = 2 - 0{\cdot}02377w. \quad \text{Consequently—}$$

$$w = 3{\cdot}23\ (2 - 0{\cdot}02377w), \text{ or}$$

$$w = 6{\cdot}46 - 0{\cdot}076777w; \text{ therefore } w = \frac{6{\cdot}46}{1{\cdot}07677} = 5{\cdot}99v \sim$$ (in round numbers, 6 metres per second).

79. Standardising the anemometer is ascertaining the relation between the velocity of the air and the number of revolutions made by the vane wheel.

Whatever instrument be used, this relation must be determined beforehand. As a rule, the operation is performed by the maker, in which event the accuracy of the anemometer can be relied on, with careful treatment, for a considerable time, since, like a watch, it is fitted with jewelled bearings. Nevertheless, it is a standing complaint against anemometers of the fan type that they register from 8 to 13 per cent. higher than the truth. This, however, will be referred to again later on.

The instrument may be tested in the following manner:—

Between the velocity v of the air and the number of revolutions N of the fan there exists the ratio $v = a + bN$. Here a and b are invariable values, which, however, differ with the delicacy of the instrument. a represents the minimum air velocity at which the fan will move at all; whilst b is a second constant relating to the same pace and the velocity of the instrument. In order to determine the value of a and b, two equations are necessary, owing to the presence of two unknown quantities. For this reason, two tests must be performed with different but known velocities. If $v = a + bN$, and $v^1 = a + bN^1$, then we have—

$$a = \frac{N^1 v - N v^1}{N^1 - N} \text{ and } b = \frac{v^1 - v}{N^1 - N}. \quad \text{(A).}$$

To apply the test, the observer carries the instrument through a closed room of large dimensions, at a uniform pace, noting down the time occupied and the number of revolutions made by the fan. It is important that the air should be perfectly still. Two tests made in this manner, at two different rates of speed, will give the values for a and b. If no large chamber is available, the test may be performed in the open air on a perfectly still day. A post is set up in the centre of an open space, and round this post is loosely slung one end of a stout cord about 5 or 6 yards in length. The free end of the cord is carried in the observer's hand, together with the anemometer, fan foremost, and he then walks round the circle described. By going twice round at different paces, the values for a and b will be furnished.

80. Whim for Testing the Anemometer.

A better method, perhaps, for testing the anemometer is by means of the same kind of whim (Fig. 35) as is used by the makers of these instruments.

The anemometer a is fixed on the end of the horizontal arm, at an accurately measured distance R from the centre of the whim shaft. The greater the value of R the better, and in no case should it be less than 4 metres. The arm of the whim can be set in motion either by the

observer or by a train of gear. As soon as the arm commences to move, the fan begins to rotate. In order to be able to start and stop the counting mechanism at any moment during the observation, the arm of the whim is provided with a double lever, actuated by cords and pivoted on x, by means of which the observer can do the needful at any point.

To this testing instrument the objection has been raised that the air is at rest and the anemometer is in motion, whereas the converse is the case in actual practice; furthermore, that the air waves encounter the vanes slantwise; also, that a vortex is produced by the movement of the whim in an enclosed space, *i.e.* that the air in the testing room is not really quiescent, but moves in the same direction as the arm of the whim, the result being to influence the number of revolutions made by the fan.

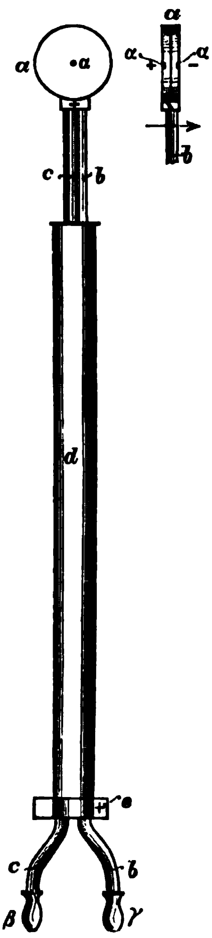

Fig. 36.

81. The Krell Anemometer.

The defects inherent in fan anemometers are claimed to be obviated in the instrument designed by Krell, and manufactured by G. A. Schultze, No. 4 Schoenebergerstrasse, Berlin; and this apparatus can also be employed to test the accuracy of anemometers of the fan type. The measurement of the velocity of air currents in the Krell apparatus is effected by determining the effort exerted by the air on the surface of a disc set up in a direction normal to that of the current.

The total effect of the air is composed of the pressure exerted on that side of the disc that receives the direct impact of the current, and of the effort of suction exerted on the rear face of the disc. That the current produces an effect of attenuation at the rear face of the disc, or sets up an exhaust action there, is evident from the fact that, when the funnel-shaped orifice of an air cowl is turned away from the ventilating current, it draws air from the shaft.

The excess pressure p_0 on the windward side of the disc amounts to $p_0 = \frac{v^2 s}{2g}$, wherein v represents the velocity of the air, s the weight of 1 cubic metre of air, and $g = 9{\cdot}808$ the acceleration of gravitation.

The effort of suction p_1 on the rearward face of the disc has been determined by numerous experiments to be $p_1 = 0{\cdot}372\,\frac{v^2 s}{2g}$. The total effect of the current is therefore—

$$p = p_0 + p_1 = 1{\cdot}372\frac{v^2 s}{2g} \text{ and } v = \sqrt{\frac{2g \cdot p}{1{\cdot}372 s}}.$$

The apparatus is shown in Figs. 36 and 37. The circular disc *a* (Fig. 36) consists of two flat chambers separated by a metal partition, the two compartments being connected below to the tubes *b* and *c* respectively. A small orifice *a* is pierced in the centre of each external face of the disc. On the side marked +, which is nearest the current, the latter exerts a force of pressure on the central partition through the orifice *a* (+),

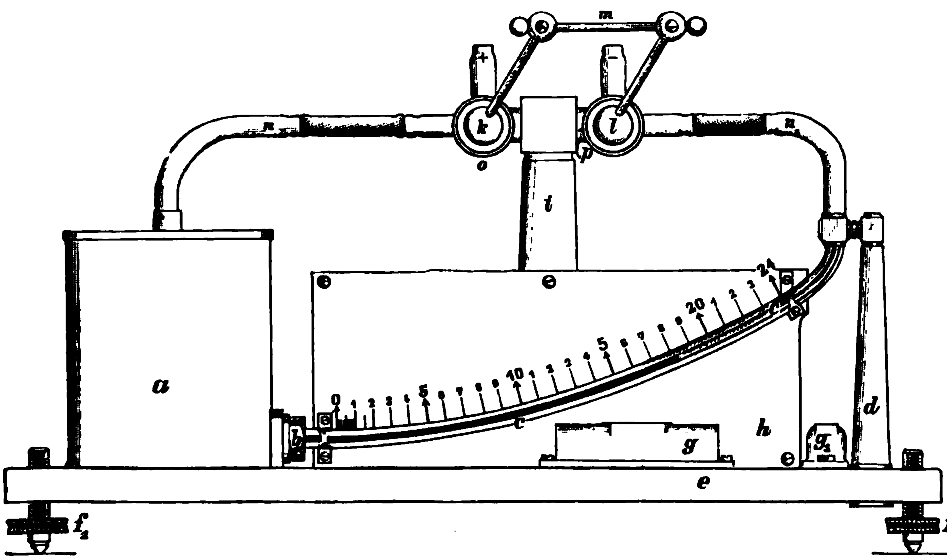

Fig. 37.

whilst on the rear face an effort of suction is exerted through the orifice (– *a*). The tubes *a* and *b* are attached at their lower ends to rubber pipes leading to the + and – terminals of the anemometer proper (Fig. 37). This latter consists of a round metal box *a*, measuring 100 millimetres in internal diameter, and forming one limb of the gauge. The second limb, in the form of a glass tube *c*, is connected with *a* by means of a stuffing box *b*. At the upper end the two limbs *a* and *c* are connected by tubes n_1 and *n* with the + and – tubes leading to the disc. By simultaneously turning the (suitably bored) taps *k* and *l*, by means of the handle bar *m*, the box *a* and tube *c* may be put in communication either with the tubes *b* and *c*, or with the chambers of the disc *a* (Fig. 36), or with the open air. In the former case the pressure

and suction of the air current are indicated on the scale attached to the tube c (Fig. 37), and in the second case the level of the liquid in the tube c sinks to zero. For the purpose of horizontal adjustment the apparatus is fitted with two spirit levels g, g_1 set at right angles, and with three set screws, only two of which (f and f_1) are shown in the drawing. As a rule, the instrument is charged with alcohol of specific gravity 0·8 instead of water.

The following table gives the vertical heights of the column of water corresponding to given velocities of the air current, the calculation being based on the formula $p = \dfrac{1{\cdot}372v^2s}{2g}$:—

Velocity, v, of Air Current.	Height of Water Column corresponding to $p = \dfrac{1{\cdot}373 \times 1{\cdot}2256v^2}{2g}$.	Height of corresponding Alcohol Column, according to the Formula $p = \dfrac{1{\cdot}373 \times 1{\cdot}2256v^2}{0{\cdot}8 \times 2g}$.
0	0·000	0·000
1	0·085	0·107
2	0·342	0·482
3	0·770	0·963
4	1·370	1·712
5	2·140	2·675
6	3·082	3·853
7	4·195	5·244
8	5·482	6·853
9	6·935	8·669
10	8·562	10·703
11	10·360	12·950
12	12·392	15·490

As may be seen from the table, the increased height of the column of water or alcohol is greater than the corresponding increase in the velocity of the air current. Thus, as the velocity increases from $v = 0$ to $v = 1$ metre, the height of the water column increases only 0·085 millimetre, whereas between $v = 9$ and $v = 10$ the increase amounts to 1·627 millimetres. On this account, the measuring tube c has to be bent more sharply upwards towards the right-hand side, and take a more horizontal position towards the left.

81*a*. Standardising the Krell Anemometer.

To standardise the Krell anemometer, a sufficient quantity of liquid (water or alcohol) is poured into the box c to reach the zero point on the scale. Since the internal diameter of c is 100 millimetres, the cubical capacity will be 78·5397 cubic centimetres. On multiplying this figure by the values given for the different velocities in the above table, and running the resulting volume of liquid into the apparatus, the different

graduations of the scale will be ascertained. For instance, the graduation for $v = 5$ metres per second will be found by placing $78{\cdot}5397 \times 2{\cdot}675 = 21{\cdot}009$ cubic centimetres of alcohol in the box *a*. The intermediate graduations are obtained by dividing the interval between each pair into 5 equal parts; and, by again dividing each of these, tenths of a degree are obtained.

When the disc of this apparatus is set up in a suitable manner in an air way, or the air conduit of a ventilating fan, the gauge itself can be put

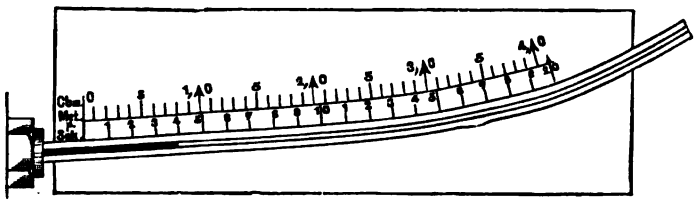

FIG. 38.

in position aboveground and connected with the disc by a pipe. Moreover, since the diameter of the air way is constant, the velocity scale of the gauge may be supplemented by a second scale indicating the cubic volume of air passing through the air way per second (see Fig. 38).

82. METHOD OF USING VANE ANEMOMETERS.

Not all positions in the pit, shaft, cross drivage, drainage gallery, or air way are equally suitable for measuring the air current; for just as in a river there may be rapids, dead water, vortices, damming-up, and backwater currents, all of which aggravate the difficulties of measuring the flow, so also in the pit there are places where the accurate measurement of the air current is wellnigh impossible, and therefore must, as far as possible, be avoided in the performance of that task.

Errors in measurement are particularly liable to occur in and adjoining curves and at air doors. A straight portion of the heading should be selected, where the walls are smooth and the way clear, and, under certain circumstances, it is necessary to line the roof, walls, and floor with boarding[1] for a distance of 4 to 8 yards, to facilitate the parallel and uniform flow of the air; and a small recess is hewn in one of the walls at the end of this lined section, so that the observer may take his measurements without himself obstructing the current. It must also be borne in mind that the velocity of the air is not the same in all parts of the

[1] *Translator's Note.*—In some of the pits in the Dortmund district, oiled or tarred canvas, mounted on a wooden frame, is used in lining the galleries at certain places where the velocity of the air current is to be measured.

sectional area of a shaft or heading, some exhibiting a maximum rate of flow, others a minimum. The maximum, too, is not always found in the centre of the passage, though as a rule the velocity diminishes in the vicinity of the walls and floor, owing to the frictional resistance there. The time at which the measurements are made is by no means immaterial. Where traffic is brisk in the shaft and haulage ways it is scarcely possible to take accurate measurements, since, when the winding shaft is utilised as an intake or upcast for air, the movement of the current is disturbed by the ascent and descent of the cages; and, again, the moving trains of trucks in the haulage ways produce occasional obstructions, thus damming up the air current and causing an irregular, pulsating flow. These pulsations are also a source of danger, since they not only stir up deposited coal dust far more than shot firing, but tend to force the lamp flames through the gauze, in fiery pits.

The measurement of the ventilating current can be performed in two different ways with the anemometer. In the first method (that of Combes) the instrument is set up in a fixed position. In a gallery of large section (see Fig. 39) two horizontal laths are fixed up—one at two-thirds and the other at one-third the vertical height of the heading. The anemometer is then placed successively at three equidistant points on each lath, and the mean of the six results is taken. A surprising difference is often found in the individual measurements at the different points. Particulars of the observations conducted in a heading 1·8 metres (6 feet) high and the same width (see Fig. 39), the superficial area being 3·24 square metres, are given below:—

No. 1 = 1576 revolutions. No. 2 = 1602. No. 3 = 1625.

No. 4 = 1557 revolutions. No. 5 = 1383 revolutions.

2 : 3133 2 : 2985

1566 1492

No. 6 = 1410 revolutions.

2 : 3035

1517

Mean of 1, 2, 3 = $\frac{4803}{3}$ = 1601.

Mean of 2, 3, 4 = $\frac{4350}{3}$ = 1450

2 : 3051

1525 revolutions, or 1525 metres in 5 minutes (300 seconds). Hence the mean velocity per second is $\frac{1525}{300}$ = 5·08 metres.

In this instance the maximum velocity was near the roof, the minimum near the floor; but this is not always the case.

Example II. (Fig. 40)—

In galleries of small diameter, four observations, as in Fig. 40, are considered sufficient. The following values are obtained, for instance:—

No. 1 = 2990 revolutions.	No. 2 = 4295.	Mean = 3642 revolutions.
No. 3 = 3695 „	No. 4 = 4300 „	= 3997 „
2 : 6685	2 : 8595	2 : 7639
3342	4287	3819 „

3819 revolutions in 10 minutes (600 seconds) give $\frac{3819}{600} = 6{\cdot}3$ metres as the mean velocity of the air current per second.

Another method of using the anemometer owes its origin to the ingenuity of an Englishman. In this case the instrument is held in the hand with the vanes pointing towards the advancing current, and is then moved to and fro for some time in a sinuous line across the heading, as shown in Fig. 41. The operation requires a little skill, which, however, can soon be acquired by practice. Two observers are desirable—one to carry the anemometer, and the other to look at the watch, start the counting apparatus, and stop same after the lapse of a given interval (one minute). A single observation taken in this manner is worth more than six on the other plan. By repeating the operation several times and taking the mean of the results, errors are almost entirely precluded.

A superficial and approximate estimation of the ventilating current can be made, in passing through the pit, by making a few observations here and there with the anemometer, at apparently suitable places, where the current is presumably strongest. To obtain therefrom the mean air velocity, the results are multiplied by 0·75 for timbered headings, 0·8 for unlined galleries, and 0·85 for galleries lined with masonry. These measurements are naturally only of value for comparison with others previously made, and can be dispensed with by those accustomed to the work, experience in gauging the velocity of the current being quickly acquired.

When the velocity is too slight to overcome the frictional resistance offered by every vane anemometer, recourse must be had to the methods described under A.

CHAPTER IV.

DETERMINATION OF THE RESISTANCE OPPOSED TO THE PASSAGE OF AIR THROUGH THE PIT—LAWS OF RESISTANCE AND FORMULÆ THEREFOR.

FLUCTUATIONS IN THE TEMPERATURE OF A PIT.

83. When the volume and pressure of the ventilating current have been determined, there still remains for estimation the resistance which the pit workings oppose to the passage of any given amount of air. It is in accordance with the laws of nature that air, in passing through a conduit, has to overcome a certain resistance, no matter of what material the walls of the conduit may consist. Consideration indicates, and experiment confirms, that the velocity attained by a current of air flowing under pressure through a conduit is not entirely dependent on the pressure employed. The loss of a portion of the velocity may be referred to a partial loss of pressure, which can only be due to a resistance to be overcome. Daubisson has offered the following explanation:—Since the resistance originates in friction against the walls, it is also proportional to the extent of those walls, *i.e.* their length and dimensions. On the other hand, the larger the diameter of the heading the smaller will be the number of molecules concerned in the resistance and friction produced by contact with the sides, and consequently the less will each molecule and the entire mass of flowing air be retarded. Hence the resistance will be in inverse ratio to the number of molecules and the sectional area of the gallery. Finally, also, as numerous experiments have shown, the resistance is directly proportional to the square of the velocity.

If, therefore, B be employed to indicate the length of the conduit or gallery, S the diameter, P the circumferential measurement of same, and v the velocity of the air current, the formula for the resistance will be as follows: $R = \frac{LP \times v^2}{S}$. (1)

This equation expresses, perhaps, the aforesaid relation between the

individual factors, but not their actual value, and the latter must be ascertained by direct experiment. All the tests that have been made on this point show that the resistance of air in a pipe is directly proportional to the length and other dimensions of the pipe and the square of the velocity, but inversely proportional to the section.

In addition to the length, shape, and dimensions of a conduit, the natural conditions of the walls thereof (inequalities, roughness, etc.) must be taken into consideration. If one merely had to do with actual mains of iron, earthenware, cement, or the like, all that would be necessary in testing would be to mount a pressure gauge at either end, the difference between the initial and final pressure then indicating whether any loss had occurred in traversing the conduit. The difference in pressure h between the two ends of the conduit being known, the following equation can be set up:—

$K = \frac{h \times S}{LPv^2}$. In the case of smooth iron pipes, K has been found constant at 0·0037, h being expressed in millimetres of water gauge. The other values are also metric.

Now, since the shafts, galleries, cross drivages, etc. going to make up a pit are really nothing but a more or less regular succession of pipes, the air passing through them is also subject to the same laws as in pipes, and consequently the resistance opposed to the passage of the air will be—

$$h = K \times R = \frac{LPv^2K}{S}. \qquad (2)$$

We shall see how this value K has been determined.

84. Resistance to the Passage of Air in Galleries.

When, for two different cases, we presuppose in the above formula No. 1 $\left(K = \frac{LPv^2}{S}\right)$ one and the same length of gallery and the same air velocity, it will be recognised that the ratio $\frac{P}{S}$ is a weighty factor in the resistance. The relation of the resistances is $R : R_1 = \frac{P}{S} : \frac{P^1}{S^1}$. If now the gallery be of square section, the periphery P will be four times the length of one side, and the sectional area S will be equal to the square of the side, *i.e.* $\frac{P}{S} = \frac{4c}{c^2} = \frac{4}{c}$.

If the section be a circle, then the circumference is $=\pi D$, and the area $\frac{\pi}{4}D^2$. Hence, then, $\frac{P}{S}=\frac{\pi D}{\frac{\pi}{4}D^2}=\frac{4}{D}$.

The ratio $\frac{P}{S}$ is therefore the same for a square or circle, provided the latter be inscribed in the former (Fig. 42).

Mining galleries are usually rectangular. If, then, the height be represented by h, the width by b, we have $\frac{P}{S}=\frac{2(h+b)}{b\times h}$. Assuming $h=\frac{3}{2}b$, then $\frac{P}{S}=\frac{5b}{1\cdot5b^2}=\frac{0\cdot333}{b}$.

If we now suppose a circle the diameter of which is equal to the height of a rectangular gallery, *i.e.* $D=\frac{b+h}{2}$, we then have—

$$\frac{P}{S}=\frac{\pi\times\frac{b+h}{2}}{\frac{\pi}{4}\left(\frac{b+h}{2}\right)}=\frac{4}{\frac{b+h}{2}}=\frac{8}{b+h}.$$

Taking $h=1\cdot5b$, as above, then $\frac{P}{S}=\frac{3\cdot2}{b}$. The ratio of the rectangle to the circle is therefore $\frac{3\cdot33}{3\cdot2}=1\cdot0415$.

Under the above presumptions for a rectangle, we may also assume a circle the diameter of which is equal to the mean of the height and width of the gallery.

Frequently $h=1\cdot25b$. On using the same calculation as above, it will be found that $\frac{P}{S}$ for the rectangle behaves towards $\frac{P}{S}$ for the circle as $3\cdot6:3\cdot55=1\cdot044$. Here also we may therefore substitute the circle for the rectangle. The diameter of a circle that can be substituted as equal to the mean of the height and width of a rectangular mine gallery varies from about 2 metres downwards to 0·75 metre. Within these limits the values for $\frac{P}{S}$ are as follows:—

$D=2$ metres	$\frac{P}{S}=2\cdot000$
„ $=1\cdot75$ „	„ $=2\cdot287$
„ $=1\cdot50$ „	„ $=2\cdot666$
„ $=1\cdot25$ „	„ $=3\cdot236$
„ $=1\cdot00$ „	„ $=4\cdot000$
„ $=0\cdot75$ „	„ $=5\cdot315$

The resistance of the mine, which is also proportional to $\frac{P}{S}$, is likewise in proportion to the above values. Therefore, in the case of a gallery of circular section with a diameter $= 1$, the resistance would be twice as great as for one with a diameter $= 2$.

When similar galleries, but of different dimensions, have to be compared, the ratios, in view of the fact that the circumferences are proportional to the homologous sides, and the sectional areas to the squares of these sides, would be—

$$R : R_1 = \frac{P}{3} : \frac{aP}{a^2S}, \text{ or } R : R_1 = \frac{P}{3} : \frac{P}{aS}.$$

If only the sides of the square $a = 2, 3, 4$ be taken, then the resistance will be $\frac{1}{2}, \frac{1}{3}, \frac{1}{4}$. The ratio $\frac{P}{S}$ is therefore very important.

Determining the Coefficient of Resistance K of the Mine.

85. In the foregoing formula (2) for the resistance : $h = \frac{LPv^2K}{S}$, the value corresponding to the truth for K must be known; and we shall see that it is not difficult to ascertain this value by certain observations, the results of which will be given.

A direct relation exists between the air pressure, or rather between the diminution of tension produced by the passage of air through the mine, and the resistance. This diminution of tension (which is often termed depression) can be expressed in millimetres of the water gauge. The equation (2) for h then assumes the following form :—

$$h = \frac{KLPv^2}{S} \text{ millimetres water gauge.}$$

Hence—

$$K = \frac{hS}{LPv^2}. \qquad (3)$$

By determining the values for h, S, L, P, and v^2, for a certain air way in the pit, the value of K would then become known. The headings and air ways in mines, however, are never of so uniform a character as the walls of a smooth pipe. As a rule, though the galleries alter both in their character and dimensions, these modifications retain a certain regularity for a definite distance; and this is sufficiently the case to enable K to be determined. Ordinarily, the ventilation in the pit proceeds in the following manner :—The current descends through a shaft, traverses the workings in a series of galleries of divergent length, section, and circumferential dimensions, until at length it is discharged into the open

air through a second shaft. To carry out the tests for determining the value of K, it is necessary to have a series of galleries and working places of different sectional areas, connected in succession and in such a manner that the differences in the tension of the air current can be determined with a pressure gauge at both ends of the series. It is also advisable that the series of galleries should be all in the same horizontal plane, so as to be able to disregard the influence, on the movement of the air current, of the differences in density between two columns of air at different levels. These two air columns of different density are constituted by parts of the general ventilating current situated between the deepest point of the intake shaft and the highest point of the upcast shaft, *i.e.* between the points *a* and *b* of Fig. 43, Plate VIII.

In many pits with a so-called central arrangement of the shafts, where the intake shaft P (Figs. 44 and 45) and the upcast P^1 are separated by only a short distance, about 30 to 50 yards, and are connected by cross drivages with the other parts of the workings, the drainage galleries, inclines, air ways, etc., the shafts themselves are connected at the deepest point by a short straight heading, which is kept tightly closed by means of air doors *q*. It is evident that by means of a pressure gauge set up at *q*, in one of the short connecting galleries P P, the total diminution of pressure H, sustained by the air current in passing from the foot of the intake shaft P through the whole of the workings up to the upcast shaft P^1, can be measured in millimetres of the water gauge. This diminution of pressure is equal to the sum of all the resistances arising in the long path P, *a*, *b*, *c*, *d*, P^1.

These resistances are as follows:—

$$(1)\ \text{From P to } a = h = \frac{LPv^2K}{S}.$$

$$(2)\ \quad ,,\quad a \text{ to } b = h_1 = \frac{L_1P_1v_1^2K}{S_1}.$$

$$(3)\ \quad ,,\quad b \text{ to } c = h_2 = \frac{L_2P_2v_2^2K}{S_2}, \text{ etc.}$$

Finally, therefore, we have—$h + h_1 + h_2 \ldots = \text{H}$, *i.e.* the air pressure, indicated by the pressure gauge set up at *q*. Consequently we have—

$$\text{H} = \text{K}\left(\frac{LPv^2}{S} + \frac{L_1P_1v_1^2}{S_1} + + \ldots\right), \text{ or—}$$

$$\text{K} = \text{H}\left[\frac{S + S_1 + S_2 + +}{LPv^2 + L_1P_1v_1^2 + +}\right].$$

We can now determine K in each heading by measuring the length, circumference, and area; and, with the aid of an anemometer, the velocity, or rate of ventilation per second, can be ascertained as well.

The air velocity cannot, however, be at once assumed as v, v_1, v_2, etc., owing to the fact that losses of air may be sustained on the way by the packing, air doors, etc.

Experiments for ascertaining the value of K have been performed with great care in different countries and districts. According to Raux, the following results have been obtained :—

1. In the Crache-Pisquery pit, in a	1600-metre	gallery	K = 0·001819.
2. Grand Buisson	„ 1680	„	„ 0·001656.
3. Torchies	„ 2695	„	„ 0·001600.
4. „	„ 3200	„	„ 0·001830.

In any event these values come very near the truth, the difference between the highest and lowest (0·00183 and 0·001600) being only 0·00023, and therefore very small.

Similar values for K have been found in other experiments in France and England.

Devillez gives the following values, for instance :—

For a whole pit	the value of K was found	= 0·0018.
For the working places	„ „ „	0·0027.
For galleries and air tubbings	„ „ „	0·0004.

In English pits Elwen found—

1. For untimbered headings in the coal, of uniform section	K = 0·00055.
2. „ „ „ of irregular section	„ 0·00069.
3. „ „ „ with very irregular walls	„ 0·00081.
4. For timbered headings	„ 0·00092.
5. For shafts with winding compartments	„ 0·00071.
6. For very irregular, untimbered headings in the coal	„ 0·00106.
7. „ „ timbered „ „	„ 0·00108.
8. Timbered way, with numerous turnings, through a pillar stall	„ 0·00263.

On the basis of his numerous researches, this observer proposed to apply the following values to K :—

For shafts	K = 0·00071.
Intake headings, drainage galleries, etc.	„ 0·00081.
For working places	„ 0·00261.
For upcast ventilating galleries	„ 0·00107.

Murgue reports as follows on the value of K :—

	Small Section.	Normal Section.
For masonry-lined headings	K = 0·00055	0·00033
„ unlined headings	„ 0·00122	0·00094
„ headings with doorpost linings	„ 0·00238	0·00156
„ perfectly straight, arched headings	„ —	0·00033
„ somewhat crooked, arched headings	„ —	0·00051
„ very crooked headings	„ —	0·00062

Although considerable divergences as regards curvature, fluctuations in diameter, and the rough character of the gallery walls exist in different pits, it is evident from the foregoing that the corresponding values of K remain fairly constant. The explanation of this is found in the circumstance that, whereas the tests for determining the resistance in pipes of small diameter (20 to 40 millimetres) were made with comparatively short lengths of pipe (100 to 120 metres) and with high velocity currents (20 to 60 metres per second), the conditions in the pit are altogether different. In the latter case we have to deal with wide galleries bearing no comparison at all to narrow pipes, but with low velocities and long lengths of gallery. Consequently in the pit the normal resistances, caused by the circumference and section of the galleries and the velocity of the current itself, predominate, and outweigh the abnormal resistances due to roughness of walls, sharp turns, etc., and throw them quite into the background; the result being that the resistance does not differ greatly in various pits, despite the divergent character of the galleries therein. One is therefore in a position to calculate the resistance with sufficient accuracy by the aid of the formula given above, in conjunction with the values found for K. It is nevertheless an undoubted fact that irregularities in the air ways influence the resistance, and that there is every reason why these irregularities should be avoided as far as possible in practice. On this account, masonry-lined galleries are preferable to all others as air ways, in virtue of their smoother walls.

86. The Coefficient of Resistance K_1 in Shafts.

The values given above for K apply to galleries; but it is by no means less useful to determine the same for shafts, the resistance to be attributed to the latter being found by deducting the resistance in the galleries from the total resistance in the pit.

The values for K in shafts also fluctuate considerably, owing to the frequency with which the aperture of the shaft is more or less obstructed. Many shafts contain passage ways and platforms with apertures for the ascent and descent of the miners, the air being also obstructed by traverses, pipes, etc. in the shaft. Moreover, the cages pass up and down the compartment allotted to them, and thus exert a disturbing influence on the regularity of the ventilating current. Guibal gives 0·001 as the general coefficient of K in shafts; but for brick-lined shafts, perfectly free from any obstruction, it may be set down as 0·0004.

According to Deville, the coefficient K for the entire pit (galleries and shafts included) is now generally assumed as 0·0018.

87. Examples of the Coefficients of Resistance.

We have already seen that the pressure necessary to overcome the resistance to the passage of air through the pit amounts, according to equation (2), to $h = \frac{0 \cdot 0018 LPv^2}{S}$ millimetres of water gauge.

If the velocity v be replaced by the volume Q of air passing per second, expressed in cubic metres, we have—

$$\text{since } Q = vS \text{ and } v^2 = \frac{Q^2}{S^2},\ h = \frac{0 \cdot 0018 LPQ^2}{S^3} \text{ millimetres.} \qquad (4)$$

According to this equation, the cube of the sectional area of the gallery is in inverse ratio to the resistance h, whereas the length of the air way, the circumferential measurement of same, and the square of distance traversed per second, are in direct relation thereto. The importance of this equation for practical pit management is shown below. Say that the resistance h is to be determined for a case where 4 cubic metres of air per second are required to traverse a gallery or series of galleries 2000 metres in length and of the dimensions shown in Fig. 46—

$$P = 1 \cdot 5 + 1 + 2 \times 1 \cdot 62 = 5 \cdot 74 \text{ metres.}$$

$$S = 1 \cdot 6\left(\frac{1 + 1 \cdot 5}{2}\right) = 2 \text{ square metres; therefore—}$$

$$h = \frac{0 \cdot 0018 \times 2000 \times 5 \cdot 74 \times 16}{8} = 41 \cdot 3 \text{ millimetres.}$$

It is evident that, if the length to be traversed is doubled, the resistance will also be doubled.

If it were desired to pass 8 cubic metres instead of 4 cubic metres of air per second through a gallery like that in Fig. 46, the resistance

$$h = \frac{0 \cdot 0018 \times 2000 \times 5 \cdot 74 \times 8^2}{8} = 165 \cdot 2 \text{ millimetres}$$

would be fourfold.

Assuming, further, that the dimensions S of the gallery were something like those in Fig. 47, the volume of air, however, remaining 8 cubic metres per second, then the following result would be obtained:—

$$P \text{ would be} = 7 \cdot 60 \text{ metres.}$$

$$S = 3 \cdot 465 \text{ square metres.}$$

$$h = \frac{0 \cdot 0018 \times 7 \cdot 6 \times 2000 \times 8^2}{41 \cdot 60} = 42 \text{ millimetres, which is only a trifle}$$

more than in a gallery of 2 square metres section; but in the latter case, with an air velocity of 8 metres per second, the resistance is fourfold, though the ratio between the areas of the two is only 2 : 3·465, or

1 : 1·732. This ratio is graphically shown and expressed in figures in Fig. 48.

This shows at a glance the great advantage to ventilation ensuing from an increase of the sectional area of the air ways. Another point of superiority of wider air ways may also be mentioned. The losses of air by escape through packing, through the goaf, timbering, brattices, and air doors, increase in direct ratio to the difference of pressure existing between two adjacent air currents, and may reach such an extent that it becomes impossible to carry a supply of air to distant working places. This circumstance becomes particularly and unpleasantly apparent in the ventilation of long blind galleries, where the tubbings used to convey the air to and fro offer an excessive resistance on account of their small diameter, quite apart from the consideration that an insufficient diameter for the tubbings causes an abnormal increase in the consumption of motive power. This question will be reverted to later on.

THE TEMPERAMENT $\left(T=\frac{Q^2}{h}\right)$, RESISTANCE $\left(R=\frac{h}{Q^2}\right)$, AND THE EQUIVALENT ORIFICE $\left(a=\frac{0{\cdot}38Q}{\sqrt{h}}\right)$ OF THE PIT.

88. The Temperament.

In the foregoing equation No. 4, $h=\frac{0{\cdot}0018PLQ^2}{S^3}$ or $\frac{KPLQ^2}{S^3}$, the values for K, P, L, and S^3 are invariable so long as no alteration occurs in the condition of the pit. For this reason the factor $\frac{KLP}{S^3}$ may be replaced by a constant R, and the equation written—

$$h=RQ^2. \qquad (5)$$

When any change occurs in the pressure h producing the air current, then a corresponding alteration occurs in Q^2 or Q, and this applies, naturally, whether the ventilation be due to suction or compression. In the former event an attenuation (depression) of the air will be set up in or above the upcast shaft of the value h, whereas the ordinary atmosphere prevails in the intake shaft; in the second case a compression h exceeding the atmospheric pressure is produced in the intake shaft, whilst the ordinary pressure obtains in the upcast shaft. In any case the motive power for producing the ventilating current resides in the pressure h, and on this, in conjunction with the subsidiary hindrances, depends the value of Q^2 or Q, the volume of the air.

If now h be changed into h_1, then RQ^2 changes into $RQ_1{}^2$. If the

equation $h = RQ^2$ be divided by $h_1 = RQ_1^2$, then $\frac{h}{h_1} = \frac{Q^2}{Q_1^2}$; furthermore, $\frac{h}{h_1} = \frac{Q^2}{Q_1^2}$. That is to say, the value of $\frac{Q^2}{h}$ is unalterable so long as the condition of the pit remains unchanged.

This unalterable value of $\frac{Q^2}{h}$ has been termed by Guibal the temperament T of the pit; so that T also $= \frac{Q^2}{h}$ (No. 7).[1]

The expression temperament implies the greater or smaller resistance encountered by the ventilating current in its passage through the workings, which resistance naturally varies in different pits.

Comparison of the Temperament of various Pits.

89. The smaller the power required to force the ventilating current through a pit the better the temperament of that pit, and *vice versâ.*

In comparing the temperament of different pits, let us assume that in one $T = \frac{Q^2}{h}$, therefore $Q = \sqrt{Th}$; whilst for a second pit $T_1 = \frac{Q_1^2}{h_1}$, and $Q_1 = \sqrt{T_1 h_1}$. By dividing the first equation by the second, we obtain: $\frac{Q}{Q_1} = \sqrt{\frac{Th}{T_1 h_1}}$; and if h be assumed $= h_1$, then $\frac{T}{T_1} = \frac{Q^2}{Q_1^2}$ or $\frac{Q}{Q_1} = \frac{\sqrt{T}}{\sqrt{T_1}}$.

The volumes of air passing through the two pits therefore stand in direct relation to the square root of their temperaments. If the volumes Q and Q_1 be assumed as equal, then $\frac{h}{h_1} = \frac{T^1}{T}$. The temperaments are therefore inversely proportional to the resistances, or the pressures required to overcome them.

In coal pits the chief factor influencing a good or bad pit temperament is the thicknesses of the seams. Where the seams are thick the galleries are naturally high and wide. Parallel headings, *i.e.* duplicate air ways, are here abundant, since the driving of these headings is profitable; consequently the temperament is usually good. True, on account of the large number and width of the galleries, the temptation exists here to unduly extend the field of ventilation, and thus unfavourably affect the temperament; but this error can be easily guarded

[1] Demanet erroneously gives $\frac{Q}{\sqrt{h}}$ as the expression for the temperament, his formula being the root of the true one.

against by the calculations given later on. In pits with thin seams it is difficult to obtain a good temperament, especially when the bad condition of the hanging and lower walls prevents the making of wide galleries; and in such cases the extent of the fields of ventilation must be considerably restricted. Long cross drivages must be made as wide as possible and brick-lined, in order to diminish the resistance due to friction.

In the coal pits of Belgium and the north of France the temperament is usually bad, on account of the thin and often highly distorted seams. Consequently, since firedamp is also present here, very great care has had to be devoted to improving the ventilating appliances. Necessity is an excellent teacher. On the other hand, the rate of improvement has been very great in districts where thick seams prevail.

Previous to 1845, temperaments $\left(\frac{Q^2}{h}\right)$ of 1, 2, and 3 were often met with in the older French and Belgian pits. Afterwards they were gradually raised to 20, 30, and 40, the motive air pressure h being 40 to 80, and in exceptional cases even 127, millimetres water gauge. In England, where the seams are for the most part of medium thickness and fairly horizontal, temperaments of 70 to 85, and even 100, are by no means rare. In the main district of Upper Silesia, where the worked seams are all from about 8 to 30 feet thick, the pit temperaments should also be consequently good; but here the error has been committed of unduly increasing the horizontal length of the working and ventilation sections, 5000 to 6000 yards being no unusual length for the ventilating current to traverse.

According to Steinhoff, the temperaments observed at the Deutschland pit (Schwientochlowitz) and the Schlesien pit (Chropatschow) do not exceed 15, 20, and 26. Here the mean length of the air ways is 2200 to 5000 yards. It will be apparent that the belauded system of central arrangement for the shafts is not very favourable for the production of a good temperament, the intake and upcast being very close together, whilst the working field extends several thousand yards sideways therefrom, so that the air current has to make its way through an extensive area of workings and then return. A decidedly better arrangement is to have the main portion of the working field situated between the two shafts, so that the ventilating current has only to traverse the distance once, and then ascends through an upcast shaft at the other extremity of the field.

SPECIFIC RESISTANCE $R = \frac{h}{Q^2}$.

90. If in the above equation, No. 5 : $h = RQ^2$, the constant factor R be set down first, we have $R = \frac{h}{Q^2}$. (6)

In this case R expresses the specific resistance of the pit, and refers to the pressure of air necessary to force 1 cubic metre of air through the pit per second.

If, for instance, we take the air pressure h as 40 millimetres water gauge, and the volume of air passing through the pit as 20 cubic metres per second, then $R = \frac{40}{20^2} = 0{\cdot}01$ millimetre is the pressure needed to drive 1 cubic metre of air through per second.

If the pressure h pass over into h_1, and the volume of air Q into Q_1, to correspond, then $R = \frac{h}{Q^2}$, and since R is also $= \frac{h^1}{Q_1{}^2}$, it follows that $\frac{h}{Q^2} = \frac{h^1}{Q_1{}^2}$. Hence the air pressures or pit resistances vary as the squares of the air volumes passing through the pit.

THE EQUIVALENT ORIFICE OF A PIT.

91. Equivalent orifice is the term applied by Murgue to express the resistance opposing the passage of an air current through the pit, in comparison with the resistance the same volume would encounter in traversing the orifice in a thin partition. The dimensions of the equivalent orifice are calculated from the formula—

$$a = \frac{Q}{K\sqrt{2gh}} \text{ square metres.}$$

Q, as before, expresses the volume of air per second; K the coefficients of contraction and friction of the passing air current $= 0{\cdot}59$; $g = 9{\cdot}808$ the acceleration of gravitation; and h the excess pressure on one side of the partition in millimetres water gauge. Consequently—

$$a = \frac{0{\cdot}38Q}{\sqrt{h}} \text{ square metres.} \qquad (8)$$

Pits with an equivalent orifice inferior to 1 square metre were termed narrow by Murgue, those with an equivalent orifice of 1 square metre being classed as medium, and those above this figure as wide. This classification, however, is not very appropriate, since in very fiery pits equivalent orifices of 3 to 5 square metres have proved necessary,

and even in large non-fiery pits equivalent orifices of 1·5 to 2·2 square metres have been recognised as barely sufficient.

In all three of the foregoing expressions, both those relating to the temperament, resistance, and equivalent orifice respectively, it is implied that the air pressure h necessary to force a given volume of air through the pit is proportional to the square of the volume of air to be moved. From a mechanical standpoint it is desirable that the temperament and equivalent orifice a should be as large, but the pit resistance R as small, as possible.

Motive Power required for Ventilation.

92. To determine the amount of motive power required by the ventilating machinery, we must take the velocity of the air current per second $= v$ metres, the volume of air $=$ Q cubic metres, and the weight of a cubic metre of air γ; then the amount of air moved in unit time will be $= Q \times \gamma$, the mass $= \frac{Q\gamma}{g}$, and the inertia therein $= Q \times \gamma \frac{v^2}{2g}$. As the initial velocity of the air is *nil*, the necessary power L for moving the air will also be $= \frac{Qv^2 \times \gamma}{2g}$.

If we insert $\frac{v^2}{2g} = h_0$, the height or pressure of the column of air effecting the movement, we then obtain $L = Q \times h_0 \times \gamma$.

As a rule, the height of a column of air is measured with a manometer (Fig. 14), the result h being expressed in millimetres of the water gauge: this gives $\frac{h}{1000} = \frac{v^2\gamma}{2g\gamma_0}$.

Since γ_0 is the weight of a cubic metre of water, 1000 kilogrammes, we then have $\frac{v^2}{2g} = \frac{h}{\gamma}$, and $L = \frac{Qh\gamma}{\gamma} = Q \times h$ kilogrammetres per second. On dividing the last expression by 75, the result gives, in horse-power, the motive force required to move a given quantity of air.

Consequently: $L = \frac{Q \times h}{75}$ horse-power. (9)

In the event of its being desired to double the volume of air forced through a pit (the temperature remaining unchanged), the air pressure h must be quadrupled, since h increases as the square of Q. The work would then be: $L = 2Q \times 4h = 8Q \times h$. It is thus evident that, the condition of the pit being unchanged, in doubling the amount of ventilating air the consumption of motive power increases in cubical proportion.

Hence, in such cases, there is every inducement to increase the temperament of the pit, *i.e.* diminish the resistance. This result is best effected by increasing the area of the air ways, as shown in the case illustrated in Fig. 48, Plate VIII., where the sectional area of the gallery has been increased in the ratio 1 : 1·73. In such event L will be only $= 2Q \times h$, *i.e.* merely doubled.

Equivalent Volumes of Air.

93. The formula $L = \frac{Qh}{75}$ horse-power, for determining the useful effort necessary in the production of the ventilating current, has been applied by Durand for the purposes of another comparison—that of the equivalent volume. If 1 be substituted for L in equation No. 9, we have $1 = \frac{Qh}{75}$, or $Q = \frac{75}{h}$. If now it be found in a given case that the air pressure must be $h \geqq 75$ millimetres, and that consequently $Q \leqq 1$, then there is every inducement to attempt an improvement in the pit temperament or a diminution in the resistance, either by widening the main air ways, driving parallel headings thereto, splitting the air current, or finally by shortening the total length to be traversed by the air.

Loss of Motive Power through the Velocity of the Discharged Air from the Upcast.

94. Formula No. 9 expresses only the motive power consumed in overcoming the resistance of the pit, whereas, as a matter of fact, the air issuing from the upcast shaft invariably does so at some velocity, which corresponds to a certain amount of wasted motive power. For instance, if the effluent air current, to the extent of 25 cubic metres per second, be travelling at the rate of 5 metres per second on leaving the upcast, the amount of power thus wasted is equivalent to $L_0 = \frac{Q\gamma + v^2}{2g} = \frac{25 \times 1{\cdot}2 \times 5^2}{2 \times 9{\cdot}80} = 0{\cdot}05$ horse-power, and this amount must be added to the power required of the fan engine. In most cases, however, this slight extra output of the ventilating engine is disregarded.

FLUCTUATIONS IN THE TEMPERAMENT OR SPECIFIC RESISTANCE OF A PIT.

95. Variability of Pit Temperament.

The pit temperament or resistance remains unchanged only so long as the character of the workings continues unaltered. This character, however, is subjected to very many changes. In the first place, the progressive extension of the workings causes a continual increase in the dimensions and condition of the underground cavities. True, these changes proceed but slowly; but, on the other hand, there are changes which one might term diurnal, and which are the result of alterations in the sectional area of the workings, whereas the first-named are the consequence of longitudinal extensions of the galleries.

Now, the diurnal alterations are direct or indirect.

(1) During the hours of work in the pit there are times when the free passage of the headings and working places is more or less obstructed by the won coal, etc.

(2) Indirect obstruction of the headings and retardation of the air current may be caused by the presence of the miners, animals, haulage tubs, electric and other locomotives, etc.

(3) Finally, the movement of the winding cages continually alters the temperament of the pit, so that measurements of air current performed during the busy periods of work give results that are seldom uniform. and often unfavourable. In coal pits the busiest time in the shaft (winding) is also cotemporaneous with the busiest coal getting, and therefore with the largest consumption of explosives and (in fiery pits) the most voluminous liberation of firedamp, all of which operations are inevitably attended with serious contamination of the air. If, in addition, the sectional area of any of the headings becomes partly or entirely obstructed at such times, it will be far from surprising to find in many parts unlooked-for accumulations of firedamp, or thick clouds of powder smoke in which it is impossible to see farther than a couple of yards. Such conditions, when arising, must be unconditionally remedied without delay.

CHAPTER V.

MEANS FOR PROVIDING A VENTILATING CURRENT IN THE PIT.

96. Natural and Artificial Ventilating Currents.

The establishment of a ventilating current in the pit presupposes the existence of some motive power for that purpose. In many cases this power is terrestrial gravitation.

When two liquids of different densities are present in a vessel, either in the liquid or gaseous condition, the heavier of the two will settle down to the bottom, whilst the lighter will suffer displacement; the result is the production of motion. Now, in connection with pit air and atmospheric air, we have seen that the chief causes of fluctuations of density are changes of temperature and the presence of admixtures of other gases. Under certain circumstances the influence of heat, the percentage of moisture, the liberation of lighter gases, and so forth, produce a movement of the air without any artificial cause, the result being a natural draught. Even in the open air the natural wind often produces motion in localities where the air is quiescent. In investigating the natural phenomena of pit ventilation, one must begin with the most simple instances first. Such a one is afforded by the case of a shaft or a depression in the earth's surface, where only one avenue of communication with the atmosphere exists. Now, experience teaches that the air in such a depression is automatically and uninterruptedly renewed—an operation that necessitates the presence of a current, be this never so slight. These natural currents can only originate through the influence of fluctuations of temperature or density.

Air Currents in Shafts.

97. On examining a shaft in course of sinking, it will be noticed that, so long as no great depth has been attained, the air in the shaft will have for the most part the same composition as that of the

atmosphere aboveground. The deeper, however, the sinking progresses, the more apparent will become the altered condition of the air, especially at the shaft floor. Here three eventualities may arise: the air near the shaft sole is either of the same density as the upper (atmospheric) air, or it may be denser or lighter than the latter.

In the first-named case equilibrium is established, and there will be no movement, there being no present cause for the shaft air to be displaced and replaced by air from above. In the second case, the quiescence is absolute, permanent, and static. In the third eventuality the equilibrium is unstable, and the shaft air suffers displacement by air from the outside. In practice all three contingencies are encountered. Quiescence in consequence of static equilibrium often results when the surrounding walls discharge carbon dioxide, this gas collecting at the bottom, owing to its density, and forming a motionless mass. Such accumulations may prove a source of danger, to prevent which certain precautions should be adopted. For instance, the presence of carbon dioxide may be revealed by the fact that a light slowly lowered from above is immediately extinguished on reaching the gas. True, carbon dioxide is also generated by the presence of the workmen, the burning of lights, etc., but, as all these causes also produce heat, the two act in opposition, so that motion is set up.

The air in shafts is usually lighter than that of the atmosphere, for the following reasons:—(1) The terrestrial temperature, and therefore that of the earth, increases with the depth. (2) Saturation with water vapour lessens the density of the air. (3) Lighter gases (firedamp) are occasionally disengaged from the surrounding rock, and mingle, by diffusion, with the shaft air, which they consequently lighten. In such cases, the lower, lighter portions of the shaft air exhibit a tendency to ascend, whilst the heavier atmospheric air sinks downwards, the result being a current, though of course only a very slight one generally. When the temperature of the surrounding rock is high the air warmed by contact with the shaft walls ascends, whilst the cooler air in the centre of the shaft sinks. These phenomena do not exhibit any great regularity, and are easily disturbed by chance circumstances. The further the sinking of the shaft progresses, the less is an automatic ventilation of the same to be depended upon; hence, when any brisk activity is displayed in a shaft in course of sinking, especially blasting operations, whereby a large quantity of irrespirable gases is produced, the natural ventilation proves insufficient, and must be supplemented by artificial means.

Nevertheless, even in this case the circulation of air may be pro-

moted by various favourable circumstances, *e.g.* by a copious flow of water trickling down the sides of the shaft. The same object can also be furthered by setting up a brattice to divide the shaft into two air ways—one for the descending air current, the other serving as an upcast (see Fig. 49).

98. Ventilating Currents in Headings.—The same causes that disturb the equilibrium of the air in shafts also operate in headings, though only to a relatively feeble extent, since the masses of air reside in the same plane, so that differences of density only become apparent in the higher parts of the galleries. Assuming that the air in a heading is lighter than the external atmosphere, then the latter—the pressure of fluids being transmitted in all directions—descends to the bottom, whilst the lighter internal air flows along the roof (see Fig. 50). When the air in the heading is colder, and therefore heavier, the phenomenon is reversed. In either case the movements will be very slight, owing to the mutual retardation of the currents.

As in shafts, the effect may be increased by separating the two currents with a brattice (see Figs. 51 and 52). This partition may be placed either vertically or horizontally, and must be arranged in such a manner as to present a minimum of obstruction to the traffic of the heading, namely, at the side or near the floor.

In sloping galleries the conditions are similar to those in shafts.

VENTILATING CURRENTS IN UNDERGROUND CHAMBERS WITH TWO EXITS.

Natural Ventilation.

99. No great result attends endeavours to produce a circulation of air in underground chambers (pit workings) that have only a single exit. The case is, however, different when there are two exits and two separate paths for the admission and removal of the air (Fig. 53).

In this case a brisk movement, a natural circulation, occurs when the two columns of air *ac* and *cf*, situated between the horizontal levels *ab* and *cd*, and connected by a gallery below, are of different temperature, and therefore different density. Under these circumstances, as will usually be the case in winter, a current will flow, in the direction of the arrow, from the mouth of the stope towards the shaft and up the latter, the external column *ac*, which is colder and therefore heavier, driving out the warmer and lighter column of air *fe* in the shaft. In summer the conditions are reversed, and on this account

we hear miners speak of the summer and winter ventilating current of the mine.

The air in a pit is almost invariably of uniform temperature, whereas that of the outer air changes both in the succession of day and night, as also with the time of year, so that the direction of the flow also varies, though the reversal is not by any means so regular as one might suppose. For example, in the case of Fig. 53, when the current has been flowing for some time in the direction shown by the arrows, from the mouth of the stope to the shaft, and the air has become warmed through contact with the walls, reversal does not readily occur, even though the external temperature rises.

100. We will now examine a different arrangement (Fig. 54).

This is a case of two shafts, P and P_1, connected below by a gallery, but opening into the air at different levels. When the air in both shafts is of uniform temperature or density, the equally heavy columns *ad* and *be* will remain in equilibrium and no current will flow, though motion may ensue from the influence of the column *hcb* when a difference exists in the temperature of the atmosphere and the pit air. Since, mostly, the columns of air in the two shafts are not of equal density, the column of free air above P being the colder and heavier, the air usually descends the shaft P and cools this latter down. The air in the pit tends to become continually warmer and lighter, by prolonged contact with the warmer rock, by friction against the walls, by heat from shot firing, by the presence of men and animals, by the absorption of moisture up to saturation point, etc., so that the column of air in P_1 becomes warmer and produces a stronger draught. Only in summer, when the air above the shaft P becomes much warmer than the column *cb* in the shaft P_1, does a partial reversal of the current ensue and a down draught is produced in P_1. In former days, before the artificial ventilation of mines had attained its present high state of perfection, attempts were made to increase this natural circulation by erecting a chimney stack to a height of as much as 150 feet above the upcast shaft, and of the same diameter as the latter. However, this method would hardly be employed nowadays in the case of pits of any size, owing to the great expense and imperfect action, especially in the summer. In many cases the gallery connecting two shafts at the bottom is on the slope, as shown in Fig. 55, instead of horizontal. In respect of the circulation of air, such shafts behave in the same manner as though of equal depth and connected as indicated by the dotted lines.

101. Theory of Natural Draught.

Take the case, illustrated in Fig. 56, of two shafts connected by a bottom gallery and opening at different levels into the upper air. The atmospheric influence is the same at a as at b, the difference of atmospheric pressure at these two points being usually disregarded as insignificant. Draw the two horizontal lines mb and an. The solution of the problem consists in determining the weight of the column of air in each shaft, and multiplying the same with the vertical height, so as to obtain the pressure exerted on the shaft sole. As we know, the specific gravity of gases is determined by various circumstances, such as atmospheric pressure, warmth, degree of saturation with moisture, and chemical composition. In ordinary cases the specific gravity of pit air is so little changed by the admixture of extraneous gases that the density of atmospheric air can be employed as the basis of calculation of natural ventilation. In the absence of special determinations on the point, the upcast air current may be assumed as saturated with moisture ($m = 1$), whilst 50 per cent. saturation ($m = 0{\cdot}5$) may be assumed as correct for the intake air.

The weight P_1 of a cubic metre of the ingoing air can be calculated from the formula: $P_1 = \frac{P(p_1 - \frac{3}{8} \times 0{\cdot}5 \times F)}{0{\cdot}76(1 + at^\circ)}$ kilogrammes, wherein $P =$ 1·29344 kilogrammes, the weight of 1 cubic metre of atmospheric air at 0° C. and 760 millimetres pressure; p_1 the local barometer pressure on the day of the observation; F the tension of the saturated water vapour at the temperature t°; and $a = 0{\cdot}003665$. (For the value of F consult the table on p. 18.) For the upcast shaft the same formula is used, with the insertion of m (the degree of saturation with moisture) $= 1$.

Let us assume the depth of the shaft ac (Fig. 56) to be 100 metres, and the difference of level nb between the mouths of the two shafts as $= 50$ metres, the temperature of the atmospheric air as 5° C., that of the intake current being 10° C., and of the upcast current 18° C., the degree of saturation of the external air $m = 0{\cdot}5$, and that of the upcast air as $m = 1$. Then the weight of 1 cubic metre of atmospheric air is 1·2464 kilogrammes, that of the intake air is 1·2231 kilogrammes, and that of the upcast air 1·1835 kilogrammes.

The weight of the column of atmospheric air ma is therefore $= 50 \times 1{\cdot}2464 = 62{\cdot}3$ kilogrammes, that of the descending column $ac = 100 \times 1{\cdot}223 = 122{\cdot}3$ kilogrammes; the entire descending column $am + ac$ therefore weighs $62{\cdot}3 + 122{\cdot}3 = 184{\cdot}6$ kilogrammes.

The ascending column db weighs $150 \times 1{\cdot}1835 = 177{\cdot}5$ kilogrammes. Consequently the difference in pressure between the two columns amounts to $184{\cdot}6 - 177{\cdot}5 = 7{\cdot}1$ kilogrammes per square metre of superficial area. This gives a motive power of 7·1 millimetres water gauge.

If the air way cd between the two shafts (Fig. 56) be closed by an air dam d, the difference in pressure between the two columns can be measured by a tubular pressure gauge. The volume Q of air flowing per second having been determined beforehand, the temperament T, resistance R, and equivalent orifice a, of the pit can be easily ascertained.

102. Producing an Artificial Ventilating Current.

As may be gathered from the foregoing, and as experience teaches, the influence of natural ventilation is limited, and this system is only applicable in pits of small size, with shafts and galleries of large diameter and insignificant traffic, so that the temperament is high and the resistance low. In fiery coal pits, and where pit fires are liable to occur, natural ventilation is inapplicable for continuous use, since it entails contingencies (*e.g.* unforeseen or unexpected reversals of the air current, etc.) which may lead to the most serious accidents. The first idea would be to supplement the natural circulation by warming the column of air in the upcast shaft and thus making it lighter.

103. Fire Baskets.

Formerly the warming of the upcast shaft was effected on the small scale by suspending a fire basket in the shaft by means of a winch and chain. This plan, however, has rightly been prohibited, owing to its attendant dangers, since the basket might easily set fire to wooden ladders, platforms, and traverses in timbered shafts, and on the other hand the health and life of the miners might be endangered by unskilful handling of the baskets and the considerable quantities of poisonous carbon monoxide produced by the imperfect combustion of the contained fuel. Thus it may happen—and the author has actually known a case of this kind—that the rapid introduction of a fire basket into a shaft during a stagnation of the air current resulted in the column of air in the shaft being insufficiently heated, the consequence being that the poisonous gases from the fire were drawn into the workings and rendered many of the miners unconscious.

104. Warming the Column of Air in the Shaft by means of Steam Pipes.

A very usual method now employed for warming the shafts is by means of the pipes conveying steam from a boiler at bank to underground engines. However well insulated these pipes may be, a considerable loss of heat therefrom is inevitable, and is attended by a warming of the shaft and the air therein. Furthermore, it is impossible to entirely prevent leakage of hot steam from the flange connections of the pipes.

Though it cannot be denied that these steam pipes in the shaft form a cheap means of promoting an active circulation of the pit air, one must not underestimate the resulting danger that the shaft timbering may be rendered extremely dry, and therefore inflammable even to the verge of explosibility. Should, therefore, shafts traversed by steam pipes be also used for purposes of ventilation, it becomes at least necessary to prescribe that they be either brick-lined or tubbed with iron throughout, or, if timbered, kept thoroughly wetted, though this latter plan entails a partial cooling of the ascending air. Furthermore, it is found by experience that, even when sprinkling appliances are provided in such shafts, the performance of this task is frequently interrupted by obstructed pipes, etc., so that disastrous shaft fires and accidents are not precluded. For these reasons, it is impossible to speak generally in favour of the use of steam-heated shafts for ventilating purposes. Wherever possible, it is preferable not to employ them for the conveyance of main ventilating currents, and to isolate them from such currents by means of iron air doors.

105. The calculation of the mechanical effect of a shaft warmed by steam pipes may be performed by means of the formulæ and rules already given. All that is necessary is to determine the mean temperature of the shaft by thermometer readings taken at different levels, and to compare the weight of the air column—presumably fully saturated with water vapour—with that of the descending column.

106. Cooling the Descending Column of Air in the Intake Shaft.

In many cases it is possible to cool down and render heavier the descending column of air in the intake shaft, by means of a fine spray of water evenly distributed over the entire sectional area of the shaft, the descending water at the same time carrying air down with it mechanically. Apart, however, from the fact that this arrangement renders the shaft

unfit for certain other uses, *e.g.* as a winding shaft for the men, the effects produced on the ventilation of the pit are neither considerable nor lasting; in fact, the method can only be resorted to as a temporary expedient, *e.g.* during shaft sinking, working preliminary headings, etc. In the case of shaft fires, an urgent warning must be uttered against sprinkling the shaft so long as any miners remain in the affected portion of the pit; since it will be evident that the greatest danger will result to the lives of such miners, through the descending water carrying down with it the large volumes of smoke and poisonous carbon monoxide gas invariably generated in these fires.

107. Ventilating Furnaces or Fires.

Ventilation by the aid of fire was very popular until recently in the case of ore mines, and also in non-fiery coal pits, on account of its cheapness. On the other hand, the method has long been prohibited in fiery mines on account of the danger of explosion, despite all precautions. More recent experience tends to show that the system in question should be abolished even in non-fiery pits, since, in the event of an outbreak of fire in the main intake shaft, or in adjoining shafts used for other purposes, there is imminent danger of the miners being suffocated by smoke and carbon monoxide. In such event the main air current may either continue to flow in its original direction towards the upcast shaft, or may be reversed by the stronger heating effect of the conflagration—the result in both cases being that the workings fill with poisonous gases and the rescue of the miners is rendered well-nigh impossible. As an examination of the following theory of ventilation by fire heat will show, the attenuating action of the furnace seldom exceeds 20 to 25 millimetres water gauge, and is therefore insufficient when the resistance of the pit is higher than this figure, whether from the extent of the workings or any other cause. Thus, in any event, one is compelled to resort to mechanical ventilation, apart from the consideration of the dangers already mentioned in connection with ventilation by fire heat.

Nevertheless, in order to place the reader in a position to decide for himself on the advisability of ventilating a pit by warming the upcast shaft, we will now describe the theory and working of the fire-heat method.

Ventilating Furnaces Aboveground.

108. The original plan was to erect the heating furnace aboveground at the foot of the chimney stack surmounting the upcast shaft (Fig. 57),

the fireplace being mounted on one side in a short arched gallery, and connected by an arched passage-way with the stack, whilst a second, somewhat longer, passage connected the covered top of the upcast shaft with the foot of the chimney. It is evident that the effect of suction thus produced on the air in the upcast shaft was limited to the difference in weight between the heated air in the stack and that of the external atmosphere. The action could not be more than slight, the exact degree being readily calculated; furthermore, the furnace might easily be the cause of firedamp explosions in fiery pits.

UNDERGROUND VENTILATING FURNACES.

109. A far stronger effect was naturally obtainable by the use of furnaces situated underground, either at the foot of the upcast shaft or at a higher level, since in such case the whole column of air above the fire came under the heating influence of the latter.

In order to ensure complete combustion of the fuel in such a fire, and the conversion of the same entirely into carbon dioxide, it is essential that the air supply should be neither insufficient nor excessive. Provision must be made for regulating the admission of air by flaps or dampers (*s*, *s*, Fig. 55), and, on the other hand, the escape of the products of combustion must not be hindered in any way unnecessarily. The best plan is to set up the furnace in a pass-by near the upcast shaft (as shown in ground plan in Fig. 58), and at a distance of 20 to 40 yards from the latter.

By means of a double wall of masonry, with an intermediate insulating air space (see Fig. 59), it is possible to prevent undue heating of the surrounding rock, or to keep the coal from getting ignited should the furnace be located in or near a seam. The front wall of the fireplace is shut off by a strong iron plate, fitted with suitable doors, to prevent the escape of radiant heat into the stokehole; otherwise the fireman would be unable to remain there on account of the great heat.

Fig. 60 illustrates a ventilating surface of the English type, with a heating surface of about 4 square metres (43 square feet), and capable of burning about 2 cwt. of coal per hour. The circular ventilating shaft is divided into two unequal compartments by a brattice, the smaller one *p* serving for the conveyance of the waste air and the gases of combustion. The hearth F is surrounded by insulating chambers on both sides and at the top. The lateral chambers R and R_1 communicate below with the compartment *p*, and are fitted with two or three air doors, which can be opened as required for the admission of air through the

fire bars. The upper conduit A can be closed when necessary by means of a double door.

The larger compartment P of the shaft may be used for other purposes, *e.g.* as an intake air shaft.

110. The furnaces sketched above would be far too small for very large coal pits, the furnaces for the latter requiring to have a heating surface of 6, 8, or 10 square metres (65, 85, or 108 square feet), or even more. As the limit of length of a hearth, for convenience in stoking, may be fixed at about 7 feet, it follows that in large furnaces the hearths must be arranged side by side as shown in Fig. 61. In this case the ventilating shaft *Sch* is connected by a rising bricked gallery *m* with the also brick-lined furnace chamber, which is fitted with several hearths, set side by side and closed in front by doors. To keep the temperature of the stokehole C within bearable limits, a number of rectangular holes *x*, *x* are provided above the doors, and communicate with a conduit *y* (Fig. 61*c*), which discharges into the rising flue *m* (Fig. 61*a*). The holes *x* may be partly or entirely closed as required.

Theory of Furnace Ventilation.

111. As we have seen, the warming of the pit air can only be effected in the upcast shaft through which it is discharged into the upper air. About the only change produced in the pit air by this method of warming is that due to the resulting heightened temperature; and consequently the latter factor alone need be taken into calculation. The method of computation is simple, but needs some care in application. When air is heated, it expands by 0·003665 of its original volume for each degree Centigrade; and, when the air in question is contained in a cylindrical vessel of constant sectional area but variable cubical capacity, it follows that the expansion must proceed longitudinally, and that the relation between the longitudinal dimensions before and after warming must be similar to the volume before and afterwards.

The Depression (Attenuation) produced in the Shaft by a Ventilating Furnace.

112. Take the case of two shafts, communicating at the bottom (Fig. 62) and debouching into the upper air at the same level—one serving as intake, the other as upcast shaft. Let H indicate the depth of the shaft, or the height of the columns of air at different temperatures, t° and t_1°.

In order to ascertain the effect of the ventilating furnace, the two columns of air are brought to the higher temperature t_1° of the upcast shaft, so that both have the same specific gravity; whereupon the increased height of the column of air in the intake shaft will be a measure of the motive power of the furnace. The height of the upcast air column being H, the height h of the intake column at the higher temperature t_1° will be: $h = \text{H}\,\frac{1 + at_1^\circ}{1 + at^\circ}$, since: $\frac{h}{\text{H}} = \frac{1 + at_1^\circ}{1 + at^\circ}$.

The difference h_a between H and h is: $h_a = \text{H}\,\frac{(1 + at_1^\circ)}{1 + at^\circ} - \text{H}$, or: $h_a = \text{H}\,a\,\frac{(t_1^\circ - t^\circ)}{1 + at_1^\circ}$. The height h_a forms a measure of the pressure set up by the escaping air at the mouth of the upcast shaft.

Leaving aside the subsidiary retarding influences, the effluent velocity v would be—

$$v = \sqrt{2gh_a} = \sqrt{2g\,\frac{\text{H}a(t_1^\circ - t^\circ)}{1 + at^\circ}} = 4{\cdot}429\sqrt{\frac{\text{H}a(t_1^\circ - t^\circ)}{1 + at^\circ}}. \qquad \text{(A)}$$

In the event of the mouths of the two shafts not being in the same plane, and assuming the ascending column to have the temperature t_1° and measure the height H_1 (Fig. 63), which is greater than the height H of the intake shaft with the mean temperature t°, then the difference ha_1 would be—

$$ha_1 = \frac{\text{H}_1 \times a(t_1^\circ - t^\circ)}{1 + at^\circ}.$$

The difference can also be expressed in millimetres of the water gauge, in which case it is sufficient to multiply the result with the weight of 1 cubic metre of air at the temperature t_1°. If, therefore, the weight of 1 cubic metre of air at the temperature t° be expressed by p, then the weight of the air at the temperature t_1° will be—

$$p_1 = \frac{p(1 + at^\circ)}{1 + at_1^\circ}.$$

Consequently the degree of attenuation or depression h_e will be—

In the former event: $h_e = h_a p\,\frac{1 + at^\circ}{1 + at_1^\circ} = \text{H}a\,\frac{(t_1^\circ - t^\circ)}{1 + at^\circ} \times p\,\frac{1 + at^\circ}{1 + at_1^\circ}$

$$h_e = \frac{p\text{H}a(t_1^\circ - t^\circ)}{1 + at_1^\circ}. \qquad \text{(B)}$$

In the second case: $h_e = \frac{p\text{H}_1a(t_1^\circ - t^\circ)}{1 + at_1^\circ}$. $\quad$ (B_1)

From this we can also determine values for t_1°, and therefore the

temperature to which the air in the shaft must be warmed in order to produce a given depression (in millimetres water gauge).

In the first case it is found that: $t_1^\circ = \dfrac{h_e + pHat^\circ}{a(pH - h_e)}$ millimetres. (C)

In the second, that: $t_1^\circ = \dfrac{h_e + H^1pat^\circ}{a(Hp - h_e)}$ millimetres. (C_1)

From the formulæ B and B_1 it follows that, whilst every increase in the temperature in the upcast shaft is accompanied by an increased depression, this latter increase is a progressively diminishing one. Consequently it is disadvantageous to raise the temperature to any considerable extent in the upcast shaft in order to increase the volume of air drawn through the pit. This circumstance causes the practical limits of utility of ventilating fires to be soon reached, and prevents their application for overcoming high resistances.

113. *Example.*—Given 10° C. as the mean temperature t° in an intake shaft 150 metres deep, and assuming the degree of saturation of the descending air to be 0·5, then the weight of a cubic metre of such air will be (formula, sec. 70)—

$$P_2 = \frac{1{\cdot}29344(B - \frac{3}{8} \times 0{\cdot}5F)}{0{\cdot}76 \times (1 + a10)} \text{ kilogrammes.}$$

Then, assuming the local barometric pressure to be 0·744, we have—

$$P_2 = \frac{1{\cdot}29344(0{\cdot}744 \times \frac{3}{16} \times 0{\cdot}054906)}{0{\cdot}76 \times 1{\cdot}03665} = 1{\cdot}2045 \text{ kilogrammes.}$$

If the air in the ventilating shaft be warmed up to 40° C., then the depression h_e in the upcast will be—

$$= \frac{P_2 \times 150 \times 0{\cdot}003665(40^\circ - 10^\circ)}{1 + a \times 40}, \text{ or } h_e = 17{\cdot}33 \text{ millimetres water gauge.}$$

For a large coal pit such a depression would be manifestly insufficient.

If it has been found that a depression of 30 millimetres would suffice to draw the requisite amount of air Q through the pit, then the question arises to what extent the air in the upcast will need warming in order to produce this result. The problem is therefore to find the value of t_1° (in formula (C)) corresponding to $h_o = 30$ millimetres water gauge.

The answer will be: $t_1^\circ = \dfrac{30 + P_2 \times 150 \times 0{\cdot}003665 \times 10^\circ}{0{\cdot}003665(P_2 \times 150 - 30)} = 66{\cdot}67^\circ$ C.

Should a depression of 50 millimetres water gauge be necessary to effect the requisite ventilation, then the air in the upcast shaft would require heating up to 118·2° C.

ECONOMIC RESULTS OF FURNACE VENTILATION.

114. If we take the case of two shafts (Fig. 64) debouching in the same horizontal level, and let H represent the height of the warmed column of air, t° the temperature of the intake shaft and outer air, and t_1° the mean temperature in the upcast, then the volume of air forced through the pit by the difference of temperature $t_1^{\circ} - t^{\circ}$ is $Q = vS$ per second, that is to say, equal to the sectional area S of the shaft multiplied by the velocity v of the air current.

According to the foregoing formula (A)—

$$v = 4{\cdot}429\sqrt{\frac{aH(t_1^{\circ} - t^{\circ})}{1 + at^{\circ}}}, \text{ and therefore } Q = S \times 4{\cdot}429\sqrt{\frac{a \times H(t_1^{\circ} - t^{\circ})}{1 + at^{\circ}}}.$$

Now, the values S, 4·429, a, and H are invariable, and therefore the volume of air Q is proportional to the expression $\sqrt{\frac{t_1^{\circ} - t^{\circ}}{1 + at^{\circ}}}$. (D)

If the temperature of the outer air and that of the intake shaft is 10° C., and the air current in the upcast shaft be warmed successively up to $t_1^{\circ} = 30^{\circ}$—40°—50°—60°—100° C., then $t_1^{\circ} - t^{\circ} = 20^{\circ}$—$30^{\circ}$—$40^{\circ}$—$50^{\circ}$—$90^{\circ}$ C. The proportional velocities or volumes of air Q will then be: Q = 4·392—5·37—6·21—6·93—9·32.

The amount of heat consumed is also proportional to the product of the volume of air per second (Q) and the accession of temperature (10° C.).

Hence the amount of heat consumed in the foregoing cases is: 43·9—107·4—186·3—277·2—745·6 respectively, which figures in turn must be proportional to the amount of fuel consumed, and thus demonstrate the rapid increase of the consumption of the latter in relation to the corresponding volumes of air Q.

It should further be noted that, in order to force a given amount of air through the pit, a certain amount of work must be performed, and that this is proportional to the third power of the volume of air. For each of the cases under consideration the work Lr, or $Q^3 = 4{\cdot}39^3$, $5{\cdot}37^3$, $6{\cdot}21^3$, $6{\cdot}93^3$—$9{\cdot}32^3$, or $Q^3 = 84{\cdot}6$, $154{\cdot}85$, $239{\cdot}48$, $332{\cdot}81$—$809{\cdot}56$.

The ratio between the volume of air Q and the amount of heat consumed will be: $\frac{Q}{\text{Heat consumed}} = \frac{4{\cdot}39}{43{\cdot}9}, \frac{5{\cdot}37}{107{\cdot}4}, \frac{6{\cdot}21}{186{\cdot}3}, \frac{6{\cdot}93}{277{\cdot}2} — \frac{9{\cdot}32}{745{\cdot}6}$ = 0·1, 0·05, 0·0333, 0·025, 0·0125; and the ratio between the work done and the fuel consumed will be: $\frac{Q^3 \text{ or work } Lr}{\text{Heat or fuel consumed}} = 0{\cdot}9$, 1·44, 1·29, 1·20—1·08.

It is thus evident that the ventilating efficiency of fuel consumed in

a ventilation furnace varies inversely as the temperature of the air in the upcast shaft.

Practical Application of Ventilation Furnaces.

115. The following example has been arranged in such a manner as to first illustrate the effect of natural ventilation in a pit, and afterwards that of an underground ventilating furnace.

In this case also (Fig. 65) there are two shafts opening into the upper air at the same level, and connected below by a rising gallery ab. The local barometric pressure is taken as $B = 755$ millimetres. The air enters through the shaft P and escapes through P^1. The temperature at a (the foot of the shaft P) is $t' = 8°$ C., the degree of saturation $n' = \frac{2}{5}$, the temperature t'' at b (the foot of shaft P′) is 16° C., and the degree of saturation $n'' = \frac{4}{5}$.

The mean temperature t in the shaft P being 6·5° C., and the mean degree of saturation $n = 0{\cdot}5$, then the weight p of a cubic metre of air in the intake shaft P will be—

$$p = \frac{1{\cdot}29344(0{\cdot}755 - \frac{3}{8} \times 0{\cdot}5 \times 0{\cdot}0074)}{0{\cdot}76(1 + 0{\cdot}003665 \times 6{\cdot}5)} = 1{\cdot}2527 \text{ kilogrammes.}$$

In the shaft P^1 the mean temperature t'' is also 16° C., and the saturation $n'' = \frac{4}{5}$. Under these circumstances the weight p' of a cubic metre of air will be—

$$p' = \frac{1{\cdot}29344(0{\cdot}755 - \frac{3}{8} \times \frac{4}{5} \times 0{\cdot}01536)}{0{\cdot}76(1 + 0{\cdot}003665 \times 16)} = 1{\cdot}2063 \text{ kilogrammes.}$$

The mean temperature in the connecting gallery ab is 12° C., and the saturation $\frac{\frac{2}{3} + \frac{4}{5}}{2} = 0{\cdot}733.$

Consequently the weight of a cubic metre of air will be—

$$p'' = \frac{1{\cdot}29344(0{\cdot}755 - \frac{3}{8} \times 0{\cdot}733 \times 0{\cdot}01046)}{0{\cdot}76(1 + 0{\cdot}003665 \times 12)} = 1{\cdot}2298 \text{ kilogrammes.}$$

The column of air in the shaft P weighs $1{\cdot}2527 \times 200 = 250{\cdot}54$ kilogrammes, and that in $P' = 1{\cdot}2063 \times 150 = 180{\cdot}945$ kilogrammes. To the latter must be added the weight of the air in the gallery ab. namely, $1{\cdot}2298 \times 50 = 61{\cdot}94$ kilogrammes. The weight of the column of intake air is thus 250·54 kilogrammes, whilst that of the upcast column is $180{\cdot}945 + 61{\cdot}94 = 242{\cdot}885$ kilogrammes, an excess of 7·655 kilogrammes on the intake side. Accordingly $h = 7{\cdot}655$ millimetres water gauge is the cause of the natural ventilation.

The height of the corresponding column of air H_o will be $\frac{7{\cdot}655}{1{\cdot}2063}$

$= 6{\cdot}346$ metres, and this will produce a pressure generating a theoretical velocity $v = \sqrt{2g\text{H}} = \sqrt{2 \times 9{\cdot}808 \times 6{\cdot}346} = 11157$ metres. Assuming that in reality the velocity of the air escaping from the upcast shaft is only 0·5 metre, and that the sectional area of the shaft is 5 square metres, then the volume of air passing through the mine will be $\text{Q} = 5 \times 0{\cdot}5 = 2{\cdot}5$ cubic metres per second. The effluent velocity $v' = 0{\cdot}5$ metre will produce a pressure $\text{H}' = \frac{v'^2}{2g} = \frac{0{\cdot}5^2}{19{\cdot}616} = 0{\cdot}013$ metre. The tension corresponding to this pressure or weight is $0{\cdot}013 \times 1{\cdot}2063 = 0{\cdot}015$ kilogramme, or 0·015 millimetre water gauge. The total pressure h was $= 7{\cdot}655$ millimetres water gauge; the pressure absorbed by supplementary obstacles is $= 7{\cdot}655 - 0{\cdot}015 = 7{\cdot}640$ millimetres $= \text{H}''$; and therefore $7{\cdot}64 \div 7{\cdot}655 = 0{\cdot}998$ of the total pressure. The temperament T is: $\frac{\text{Q}^2}{\text{H}} = \frac{2{\cdot}5^2}{7{\cdot}640} = 0{\cdot}82$, *i.e.* very small.

If it be further assumed that a ventilation furnace is erected at b, at the foot of the upcast shaft P^1, and that by this means the temperature in the shaft is raised by 44° C., *i.e.* to 60° C., then the weight of a cubic metre of the air in such case will be—

$$p_3 = \frac{p_1}{1 + 0{\cdot}003665 \times 44} = \frac{1{\cdot}2063}{1{\cdot}16126} = 1{\cdot}0387 \text{ kilogrammes.}$$

At a depth of 150 metres the weight of the column of air is $1{\cdot}0387 \times 150 = 155{\cdot}805$ kilogrammes. On adding to this the weight of the air in ab, namely, 61·94 kilogrammes, we have the total weight of the upcast column, $155{\cdot}805 + 61{\cdot}94 = 217{\cdot}745$ kilogrammes, the difference in weight between the two columns being thus $250{\cdot}54 - 217{\cdot}745 = 32{\cdot}795$ kilogrammes. This corresponds to the pressure of a column of air $\text{h}_o = 32{\cdot}795 \div 1{\cdot}0387 = 31{\cdot}572$ metres in height, and generating a theoretical velocity of $4{\cdot}429\sqrt{31{\cdot}572} = 24{\cdot}886$. The greater part of this pressure is absorbed by supplementary obstacles, the minor portion being manifested in the form of effluent velocity. The proportion consumed by the supplementary obstacles is given above as 0·998 of the total pressure in the case of natural ventilation; consequently in the present case these supplementary obstacles absorb a pressure of $31{\cdot}572 \times 0{\cdot}998 = 31{\cdot}5 = h$ millimetres water gauge. Under the pressure necessary to overcome this, the true pit resistance, the following volume of air will flow through a pit having the temperament $\text{T} = 0{\cdot}82$, namely, $\text{Q} = \sqrt{\text{T} \times h} = \sqrt{0{\cdot}82 \times 31{\cdot}5} = 5{\cdot}08$ cubic metres per second. If the sectional area of the upcast shaft be 5 square metres, the effluent velocity will be $5{\cdot}08 \div 5 = 1{\cdot}016$ metres per second.

The total work done in the ventilation is $\text{Q} \times h_o = 5{\cdot}08 \times 31{\cdot}572 =$

160·386 kilogrammetres per second, manifested as energy in the effluent velocity. That is to say, $\frac{Pv^2}{2g}$, wherein $P = Q \times p_3 = 5·08 \times 1·038 = 5·273$, and $v = 1·016$ metres, *i.e.* $v^2 = 1·032$. Hence $\frac{Pv^2}{2g} = \frac{5·273 \times 1·032}{19 \times 62} = 0·277$ kilogrammetre.

Secondly, the supplementary obstacles also absorb work. $Q \times h = 31·5 \times 5·08 = 160·02$ kilogrammetres.

This gives together $160·02 + 0·277 = 160·297$ kilogrammetres, whereas the total work found above was 160·386 kilogrammetres. The difference is insignificant.

The energy developed by warming the upcast shaft is equal to the total energy, less that produced by natural ventilation, namely, $160·297 - 2·5 \times 7·655 = 160·297 - 19·137 = 141·16$ kilogrammetres.

Amount of Heat utilised in Ventilation Furnaces.

116. The temperature of the pit air was raised by 44° C. through the action of the furnace. This means that $5·08 \times 1·0387 = 5·2766$ kilogrammes of air were heated through 44°. Now, in order to raise 1 kilogramme of air through 1°, 0·237 calory is required. Hence in the present instance $0·237 \times 5·2766 \times 44 = 55$ calories are consumed per second, or 198,000 per hour.

Theoretical Consumption of Fuel.

116*a*. Taking the calorific power of 1 kilogramme of coal as 6900 calories, of which only 6500 can be brought into calculation, allowance having to be made for waste in falling through the firebars, then the consumption of coal in the above case would be $198{,}000 \div 6500 = 30·46$ kilogrammes per hour. As 25 kilogrammes (roughly, ½ cwt.) of coal can be advantageously consumed per square metre of grate surface per hour, the furnace must have a grate surface = 1·2 square metres, or 1½ square metres, on allowing the necessary margin for contingencies.

The energy generated by the combustion has been already given as 141·16 kilogrammetres per second, or $141·16 \div 75 = 1·88$ horse-power. Hence the consumption of coal per horse-power-hour amounts to $30·46 \div 1·88 = 16·15$ kilogrammes.

Now, in the event of an increased temperature of 100° being found necessary in order to induce the requisite volume of air to flow

through the pit, then 1 cubic metre of such air p_4 would weigh $\frac{p_1}{1+at} = \frac{1 \cdot 2063}{1 + 0 \cdot 003665 \times 100} = 0 \cdot 883$ kilogramme, and the pressure of a column of air, 150 metres high, per unit of ground surface, would be $0 \cdot 883 \times 150 = 132 \cdot 45$ kilogrammes. On adding to this the 61·94 kilogrammes corresponding to the column of air in the gallery *ab*, we have together 194·39 kilogrammes. The weight in the intake shaft remains 250·54 kilogrammes as before, so that the difference in the weight of the incoming and effluent columns of air will be $= 250 \cdot 54 - 194 \cdot 39 = 56 \cdot 15$ kilogrammes. This motive pressure corresponds to a column of air $56 \cdot 15 \div 0 \cdot 883 = 67 \cdot 407$ metres high, and this height in turn corresponds to a theoretical velocity $v = 4 \cdot 429 \sqrt{67 \cdot 407} = 36 \cdot 362$ metres.

If the supplementary obstacles (pit resistance), again, account for 0·998 of the total resistance, then the pressure thereby consumed will be $h_1 = 56 \cdot 15 \times 0 \cdot 998 = 56 \cdot 0$ millimetres water gauge. At this pressure the volume of air passing through the pit per second would be $Q_1 = \sqrt{Th_1} = \sqrt{0 \cdot 82 \times 56 \cdot 15} = 6 \cdot 78$ cubic metres: and the effluent velocity $6 \cdot 78 \div 5 = 1 \cdot 356$ metres per second.

The corresponding pressure would be: $h_2 = v^2 \div 2g = 1 \cdot 356^2 \div 19 \cdot 616 = 0 \cdot 0937$ metre, or 0·094 millimetre water gauge. On adding the pressure consumed by the pit resistance, we have the total pressure $56 \cdot 0 + 0 \cdot 094 = 56 \cdot 094$ millimetre water gauge.

The total pressure found above was 56·15, and on deducting 56·094 we have, as the difference, 0·056 millimetre.

In this case the total energy of ventilation would be $Q_1 \times h_1 = 6 \cdot 78 \times 56 \cdot 15 = 380 \cdot 697$; or, deducting the figures for natural ventilation, namely, 19·137, a total of 361·560 kilogrammetres, to express the energy developed by the furnace warmth. This value corresponds to $0 \cdot 237 \times 6 \cdot 78 \times 0 \cdot 883 \times 100 = 141 \cdot 886$ calories per second, or 510,789 per hour.

Taking, as before, the calorific power of coal as 6500 calories per kilogramme, then the consumption of coal would amount to $510{,}789 \div 6500 = 78 \cdot 57$ kilogrammes. This would require a grate surface of 3·1, or better 3·5, square metres area.

The energy developed being $361 \cdot 56 \div 75 = 4 \cdot 82$ horse-power, the consumption of coal would amount to 16·3 kilogrammes per horse-power-hour.

The results obtained by the foregoing calculations are theoretical, and are never arrived at in practice, since it often happens, especially in wet upcast shafts, that the ascending air is so far cooled down by

contact with the shaft walls that the flow is suspended and the action becomes *nil.*

Even in the case of perfectly dry shafts, the theoretical consumption of coal in the ventilation furnace is exceeded by $\frac{1}{4}$; and in wet shafts this consumption may become two-, three-, and even four-fold the calculated quantity. There is also, then, a danger of the ventilating current becoming suddenly reversed, in which event the carbon monoxide formed in the furnace would penetrate the workings and prove extremely injurious to the miners there engaged. In the most favourable cases it is hardly possible to employ ventilating furnaces at a greater depth than 300 to 350 metres (1000–1100 feet) below bank, on account of the cooling of the gases in the upcast shaft. At the Pluto pit (Westphalia) the use of a ventilating furnace at a depth of 330 metres had to be discontinued, owing to the shaft water cooling down the air to such an extent that the updraught was entirely suspended. This shaft was lined with iron tubbings, wedged with wood, but the wedges took fire and caused a deal of damage, and finally mechanical ventilation had to be employed.

Ratio between the Heat present in Pit Air and that produced in the Ventilating Furnace.

117. In every case it is possible to calculate the ratio between the warmth present in the pit air and that supplied by the fuel consumed in the furnace.

If Q, again, represent the volume of air passing through the pit per second, t° the temperature of this air, and t'° the temperature of the air after passing by the furnace, then we know that the number of heat units required to raise the weight of air pQ from the temperature t° to t'° is $0{\cdot}237\ p\text{Q}\ (t'^\circ - t^\circ)$.

The weight of 1 cubic metre of air at 0° C. and 760 millimetres pressure is 1·239 kilogrammes; the weight p at temperature t° and the pressure B is: $p = \dfrac{1{\cdot}293\text{B}}{0{\cdot}76(1+at^\circ)}$.

By replacing the value of p in the above equation, we obtain—

$$0{\cdot}237\ \frac{1{\cdot}293\text{B}}{0{\cdot}76(1+at^\circ)}\ \text{Q}(t'^\circ - t^\circ).$$

Q can be determined by the anemometer, and the other values can also be determined direct.

The heat disengaged by the fuel is $= \text{G} \times \text{N}$, wherein G represents

the weight of the fuel (in kilogrammes), and N the number of heat units furnished per kilogramme. Hence the output is—

$$R = 0{\cdot}237 \times Q \times 1{\cdot}293 \; \frac{H(t'^{\circ} - t^{\circ})}{0{\cdot}76(1 + at)6500}. \qquad \text{(E)}$$

118. Work done by a Ventilating Furnace.

The ventilative effect is expressed by the formula $A = Q \times h$ kilogrammetres. As function of the temperament we have $A = \sqrt{T \times h^3}$.

The difference between the pressure of the air at the intake and upcast shafts, or the air pressure produced by the difference in temperature t and t', which pressure is also dependent on the height H of the column of air in the shafts, is expressed by—

$$h = \frac{Ha(t'^{\circ} - t^{\circ})}{1 + at} \text{ millimetres.}$$

On substituting the value of h in the equation $A = \sqrt{T \times h^3}$, we have $A = \sqrt{T\left[\frac{Ha(t'^{\circ} - t^{\circ})}{1 + at^{\circ}}\right]^3}$ kilogrammetres per second.

From this it is evident that the work done by the warming of the air in ventilating shafts varies as the square root of the pit temperament and the root of the cubed height of the column of warmed air H, as also with the cube of the difference of temperature $t'^{\circ} - t^{\circ}$. The influence of this difference of temperature is the more favourable the lower the temperature of the pit air.

Other conditions being equal, an increased temperature not only reduces the efficiency of the ventilating furnace, but, when a given temperature is exceeded (the limit being 315° C., according to Atkinson), the strength of the ventilating current becomes progressively less, owing to the fact that, on account of its greater density, the external air descends against the sides of the ventilating shaft (see Fig. 66), especially when the shaft is comparatively wide. For this reason, upcast shafts are narrowed at the mouth.

The Practical Effects of Ventilating Furnaces in Belgium and England.

119. Experiments carried out by Glépin with ventilating furnaces at the Grand Hornu Colliery, Belgium, showed that in deep, dry shafts the loss of heat amounted to 20 per cent., and that consequently 80 per cent. of the fuel was utilised. In narrow and wet shafts, on the other hand, the loss of heat rose to 80 per cent.

In England, where ventilating furnaces were in use to a very large extent for a long period, numerous experiments have also been performed. In one furnace, 213 metres below bank, the consumption of coal averaged 18·26 kilogrammes (40·17 lbs.) per horse-power-hour, *i.e.* only a little higher than previous calculation had indicated. Nearly all English collieries have a high temperament or a low pit resistance. The following table gives three experiments performed at the Hetton, Elmore, and Eppleton Collieries.

EFFICIENCY OF VENTILATION FURNACES IN ENGLISH PITS.

Pit.	Diameter of shaft.		Velocity of air current, in metres per second.	Volume of air supplied.		Depression, millimetres water gauge.	Coal consumption.		Vertical distance of furnace from bank.	Temperature.		Height of lift H.	Pit temperament.	Force of current in horse-power.	Coal consumption per horse-power-hour.	Useful effect, horse-power.	Coal consumption per horse-power of useful effect and per hour.
	Intake.	Upcast.		Per minute.	Per second.		Per 24 hours.	Per hour.		Intake.	Upcast.						
	m.	m.		cbc. m.	cbc. m.		tons.	kgs.	m.	°C.	°C.				kgs.		kgs.
Hetton . .	3·5	4·27	6·71	4980·8	83	38	36·13	1500	274·5	7·6	129	79·33	181·3	109·3	13·7	42	35
Elmore . .	3·81	2·67	8·85	2943·2	49	25	18·77	782	237·9	5·5	149	80·88	96·0	66·2	11·8	16·33	47·[illegible]
Eppleton .	3·81	3·40	8·85	4597·8	76·6	51	37·04	1600	318·4	10	93	78·38	115	93·11	17·17	52·0	3[illegible]

CHAPTER VI.

INJECTED STEAM—COMPRESSED AIR—SEPARATE VENTILATION—ELECTRICITY IN VENTILATION.

MECHANICAL VENTILATION.

120. In the mechanical ventilation of mines the ventilating current is generated by machines driven by power. These machines may be divided into two main groups—

A. Those employed for ventilating only portions of the workings, single shafts, cross drivages, galleries, etc., and therefore having merely to produce the circulation of small volumes of air; and

B. Machines for efficiently ventilating an entire pit or section of a pit, and therefore capable of setting in motion large volumes of air.

Another method of classification is according as—

(*a*) The power—steam, wind pressure, compressed air, or hydraulic power—employed to move the air acts direct on the ventilating machine, without the intervention of a motor; or

(*b*) The machine generating the current is actuated by a motor.

Generally speaking, it may be said that all the appliances coming under the heading (*a*) are more suitable for ventilating isolated portions of a mine (separate ventilation), whilst those driven by a motor (*b*) can be more advantageously employed for ventilating the mine as a whole.

VENTILATION BY INJECTED STEAM.

121. Mention has already been made of the fact that the column of air in the upcast shaft of a mine can be warmed and caused to ascend by the warmth of a steam pipe placed in the shaft. These steam pipes, however, are primarily intended for the transmission of power, their ventilative action being merely a supplementary feature.

Attempts have, however, been made to warm the shaft air direct, or to set it in motion by an injected current of steam, in the same manner

as, in firing locomotives, a jet of steam (either direct from the boiler or waste steam) blown into the short smoke-stack causes a strong draught of air to flow through the firebars and fuel, and thus powerfully assists combustion.

On the advice of Gunot, jets of steam were used in Belgium for ventilating purposes as far back as 1841, though with little success. In 1852–53 attempts were also made in England, but also with little success.

122. Mention may here be made of a method of ventilation by direct steam, introduced by Mehu at the Grand Hornu Colliery, Belgium (Fig. 67, Plate XI.).

Steam, at a pressure of 5 to 6 atmospheres, is led through a pipe A into an arched chamber B, communicating with the ventilating shaft. The steam issues from the pipe through six jets *s*, debouching under an equal number of short, vertical pipes C. The air in the chamber B is carried away by the steam flowing through the pipes C, and is discharged into the open air above. The capacity of the installation is only 1·616 cubic metres of air per second when the pressure of the effluent air measures 16·5 millimetres water gauge.

Pelletan, under similar circumstances, used only a single jet of steam, and obtained a flow of 3·285 cubic metres of air under a pressure of 57·5 millimetres. At the No. 2 shaft of the L'Agrappe and Grisoeuil Colliery, in 1841, the steam from a boiler was conveyed a distance of 120 metres, and blown vertically upwards. The effect was very small, though greater than in the case just mentioned.

123. At the Ardenoises Colliery, near Gilly, the waste steam from the winding engine and the hot gases from a furnace were conducted into a ventilating stack 27 metres high and 2·4 metres diameter inside. Despite the shortness of the distance, the only ventilative effect produced amounted to 3·565 cubic metres of air, under a pressure of 1·5 millimetres water gauge.

Finally, at the Grand Hornu Colliery, the steam from a boiler, developing a pressure of 2¾ atmospheres, was conducted into a chimney stack 39 metres high and 1·19 metres diameter. The effective force of this steam is equal to 75 kilogrammetres per second. The boiler firing alone would furnish 1·228 cubic metres of air under a pressure of 13 millimetres water gauge, corresponding to a force of 19·812 kilogrammetres. Consequently the steam jet furnished only 19·812 $- 14{\cdot}756 = 5{\cdot}016$ kilogrammetres. The consumption of steam amounted to 7·5 cubic metres, the useful effect being therefore only 5·076 $\div 7{\cdot}5 = 0{\cdot}67$.

124. Extensive experiments have also been made with steam jet

ventilation in England. At the Hetton pit, for example, where there is only one upcast shaft to several winding shafts, the following arrangement has been adopted (Fig. 68, Plate XI.).

The waste air current ascends to the upcast shaft P through the rising galleries G and G^1. Simple ventilating furnaces F and F^1 are situated at the foot of these galleries, and two large Cornish boilers, for the haulage, are in position at the foot of the upcast P. A steam pipe *t* delivers steam from the one boiler into a multiple jet *a*, placed in the centre of the upcast shaft. There are thus several influences combined to affect the up draught in the shaft P, namely: (1) the natural draught, (2) the radiant heat from the boilers, (3) the ventilating furnaces, and (4) the steam jet *a*.

The experiments made with the steam jet showed that the effect of the jet with an increased pressure of steam varies inversely with the diameter of the jet orifice.

The ventilative effect of the furnaces was ascertained to be equivalent to 328·6 cubic metres of air per lb. of coal consumed; that of the steam jet, only 181·5 cubic metres.

125. Similar unfavourable results were obtained with steam jets at the Tyne Main and Tem Collieries. At the former the furnace gave results equal to 172·2 cubic metres of air per lb. of coal; the steam jet only 6·3 cubic metres; whilst at the second pit the results were 278 and 5 cubic metres respectively.

THE KOERTING INJECTOR (Figs. 69 and 70, Plate XI.).

126. The steam injector manufactured by the firm of Gebrueder Koerting, of Koertingsdorf near Hanover, is used for ventilating entire pits as well as for separate ventilation. The maximum capacity of the largest of these injectors (Fig. 69) is 12 to 13 cubic metres of air per second. Steam is supplied to the apparatus through the pipe *r*, and is discharged through a small orifice into a larger jet surrounding same. The air over the steam outlet is thereby highly rarefied, and more is therefore drawn in from the sides, *e.g.* the air conduit S. The jets, which are 6 to 8 in number in the larger injectors, increase in diameter in their upward serial order. The outflowing steam draws in air through the lateral orifices, and discharges the same through the flared tube at the top. This flared tube fits, by means of a bottom flange, on to a cast-iron plate, built air-tight into the brickwork lining of the air way.

The subjoined tables furnish particulars of the efficiency, etc. of a Koerting injector, erected at the Jacob shaft of the Nordbahn Colliery at

Maehrisch-Ostrau, to act as a reserve in the event of a breakdown of the fan.

Observation.	Depression h in millimetres water gauge.	Capacity Q in cubic metres of air per second.	Work $\frac{Qh}{75}$ in horse-power.	Coal consumption.	
				Per 24 hours.	Per hour for each 1 cubic metre of air per second.
				Kilogrammes.	
First . .	32	12·9	5·5	8000	25·7
Second . .	33	13·3	5·8	8300	25·9

The consumption of steam per hour amounted to 817 kilogrammes, corresponding to a 50–55 horse-power engine working without condensation.

The coal consumption of a Koerting injector is five times as great as that of a Rittinger fan, and about ten times that of a good Guibal fan. On the other hand, the Koerting injector costs only about £100, inclusive of fitting-up, or about one-fifth to one-seventh the price of a Guibal fan of the same capacity; and it also enjoys the advantage of having no moving parts, and being therefore free from wear and tear and outlay for repairs. It works in a very reliable manner, and rarely gets out of order.

The Koerting injector is used as a reserve ventilator for fiery pits in particular, for the foregoing reasons, and also because the extra coal consumption is of small moment for the short time the apparatus is in use. The injector is not mounted directly over the mouth of the upcast shaft, but a little to one side, and is connected with this shaft by a bricked culvert. The ventilating shaft is closed at the mouth by a tight-fitting cover, which can easily be replaced or renewed if blown off by an explosion.

When a supply of steam is available, small Koerting injectors, such as that shown in Fig. 70, can be used for separate ventilation, *e.g.* in shaft sinking.

The following list of Koerting injectors gives the capacity and prices of the different sizes made.

No. of Injector.	Capacity in cubic metres of air per minute.	Price, with steam valve, shillings.
1	3	70
2	6	88
3	12	103
4	25	135
5	50	220
6	100	330
7	175	440
8	250	550
9	325	810
10	400	977
11	475	1090
12	625	1415

Ventilation by Natural Pressure, with Air Cowl.

127. An old device, and one still used in mining practice, is the so-called air cowl, by means of which the natural pressure of the wind is utilised for ventilation (see Fig. 71). According as the effect is to be one of pressure or suction, the horizontal funnel on the cowl is turned towards or away from the direction of the wind. The narrow end of the funnel is bent round at right angles, and debouches into a vertical tubbing forming the air conduit. The cowl is mounted so as to be capable of rotation on the shaft tubbing, and may be fitted with vanes so as to turn automatically with every change of the wind. It is still largely used in the sinking of small shafts, and is cheap and easily made, but unfortunately suffers from the drawback of being almost entirely inoperative during a calm, its action then being confined to the effect resulting from the possible prevalence of a higher temperature within the cowl than in the rest of the shaft.

Ventilation with Compressed Air—Air Compressors.

128. Many pits, especially those of large size, are fitted with installations for compressing air, for the transmission of power to the underground workings, compressed air being well adapted for such transmission of power to great distances. Its principal application is for driving rock drills, winches, and small pumps; but may also be usefully employed for ventilation purposes, especially separate ventilation.

The compression is effected in air compressors, which are usually driven by steam power. A good compressor should fulfil the following requirements:—

(1) Occupy little space;

(2) Run at a high speed, in order to supply a large volume of air from cylinders of small diameter; and

(3) Furnish the air as dry as possible, and compressed to a tension of 4 to 5 atmospheres.

There are several types of air compressors, namely, dry-, semi-wet-, wet compressors; compressors with valve motion, and compound compressors.

Dry Compressors.

These are usually employed at collieries, because the air to be compressed does not come in contact with water, and therefore remains dry, so that when discharged from the pipes there is no formation of ice on

expansion, nor are the inner parts of the machines so liable to rust. In these compressors the cooling must be effected by water applied externally, and this at least prevents decomposition of the lubricants in the air cylinder.

The piston velocity must not be very high, since the air is only cooled down at the cylinder walls, and not in the interior.

Dry compressors may be fitted either with valves or slides; and those with valves may be single- or double-acting.

Single-acting compressors are those of Davy, Kilbourn, Wilkinson, and Gray; they are fitted with water jackets, and the compressor cylinders have double walls. Dry double-action compressors are constructed by E. W. Blanke & Co., of Merseburg, and by the Braunschweigische Maschinenbau Anstalt. A Colladon air compressor was used in constructing the St. Gothard Tunnel.

Slide-valve compressors, with pressure compensators, are made by C. W. Allen, of New York; Burkhard & Weiss, of Basle; and Klein, Schanzlin & Becker, of Frankenthal.

The advantages of these compressors include—

(1) Higher piston velocity than in valve compressors.
(2) Higher volumetric working efficiency.
(3) Smaller cylinders for an equal output.
(4) Reduced friction.
(5) Low weight and prime cost.
(6) Less expense for repairs, owing to the smaller wear and tear.
(7) Less leakage than with valves.
(8) Noiseless working.

On the other hand, the disadvantages are—

(1) Higher consumption of motive power.
(2) More extensive heating of the air.

However, efficient lubrication with good oil renders these defects insignificant.

The Weiss compressor furnishes perfectly dry air, so that the formation of ice is precluded.

Semi-Wet or Spray Compressors.

129. These are cooled by means of water jackets and by the introduction of a cold water spray, partly during the suction period, partly during compression, and in some cases during both. The small orifices used for spraying are easily choked. In order to re-dry the compressed

air, especially for use in rock drills, large air chests must be provided in connection with the air pipes.

Compressors of this type are made by Burleigh, Cornet, Dubois-François (used at Blanzy), the Humboldt Co., of Kalk (Cologne), Haertel-Meyer, Mueller, Revollier of Blanzy, and Roy of Vevey.

Wet Compressors.

130. The first compressor of this class was constructed by Sommeillier, for driving the rock drills in making the Mont Cenis Tunnel, a layer of cooling water being interposed between the water and air in the cylinder.

Advantages—

(1) More effective cooling than with water jackets.
(2) Greater volumetric efficiency.
(3) Simplicity of construction.

Defects—

(1) Low piston velocity, otherwise water knocks and priming occur.
(2) Greater dimensions and weight.
(3) Larger consumption of water.
(4) Higher consumption of motive power.
(5) Liability to formation of ice in the driven machinery, in the absence of a special furnace or stove for heating the compressed air before its discharge into the open.

Machines of this type are also made by the Humboldt Co., and by Danek of Prague. Another useful form is the vertical compressor of Hanarte (Mons).

Compressors with Valve Gear.

131. Riedler was the first to construct air compressors with valves kept open by springs, and closed by the action of special valve gear. Similar compressors are also made by Ehrhardt & Sehmer of Schleifmuehle; Breitfeld, Danek & Co. of Prague; and Dr. Broell of Dresden.

Compound Compressors.

132. The clearances in the cylinder prevent the air being compressed beyond a certain stage, the expansion of the air in the clearance retarding suction on the retreat of the piston. Since, however, a very high degree of compression is required for certain purposes, the practice has arisen of effecting the compression by stages, in two or three successive cylinders, the air compressed in the one being delivered into the next for further

compression. Thus, to compress air to 125 atmospheres in a three-cylinder machine, it is compressed to 5 atmospheres in the first cylinder, then to $5 \times 5 = 25$ atmospheres in the second, and finally to $25 \times 5 = 125$ atmospheres in the third. To obtain this result, the air is either passed direct from the first large cylinder into the second and smaller one, or, in order to secure more efficient cooling, is made to traverse an intermediate chamber. This method of compression by stages was first employed by Colladon in the construction works at the Mont Cenis Tunnel, for driving the compressed-air haulage locomotives at a working pressure of 16 atmospheres.

Riedler was the first to apply the system to the transmission of power. Air compressors without an intermediate chamber are made by Brotherhood of London (for torpedoes), Whitehead, Sergeant (New York), Blythe (London), and others. Those of Hunarte, Kaselowsky (Berlin), and Riedler are fitted with intermediate chambers for cooling.

The Riedler machine is well adapted for pit work. The one in use at the Dieplinchen pit, near Stolberg, has two single-acting cylinders fitted with geared clack valves, and has a capacity of 6 cubic metres of air per minute under an absolute pressure of 6 atmospheres. The dimensions are as follows:—

High-pressure steam cylinder, diameter . .	350 millimetres.
Low- ,, ,, ,, . .	500 ,,
Low-pressure air cylinder, diameter . .	530 ,,
High- ,, ,, ,, . .	340 ,,

Stroke, 500 millimetres; Speed, 60 revolutions per minute.
Boiler, pressure $5\frac{1}{2}$ to 6 atmospheres.
Steam consumption per horse-power-hour, 9 kilogrammes.
Capacity of steam engine, 43 horse-power.

In the improved Riedler compound compressor the output is 10·4 cubic metres of air under a pressure of 6 atmospheres per horse-power-hour; in the others, only 7·5 to 8·5 cubic metres.

Dimensions of Air Mains.

133. As compared with an equal volume of distilled water, the weight of dry atmospheric air at 0° C. and 760 millimetres pressure is $\frac{1}{773}$.

Under the same conditions of temperature and pressure, the weight of 1 cubic metre of dry air is 1·29381 kilogrammes; but at the temperature $t°$ and the pressure B it amounts to—

$$\frac{1 \cdot 293B}{(1 + 0 \cdot 003665t°)0 \cdot 760} \text{ kilogrammes.}$$

The mains used for compressed air are usually made of cast-iron, the branches of wrought-iron. The cast-iron pipes are in lengths of 3 metres (10 feet), 180, 140, or 120 millimetres wide (7, 5½, or 4¾ inches), with flanged connections, fitted with springs, grooves, and rubber washers. The wrought-iron pipes are in lengths of 5 to 6 metres (16 to 20 feet), and 100, 88, 60, 40, and 20 millimetres (3¼, 2¾, 2, 1⅜, and ⅝ inches) in diameter, with loose flange joints, the smaller sizes screwing together. When the joints are well made the loss of pressure amounts to 0·25 to 0·2 kilogramme per 1000 metres of pipe, or 5 to 6 per cent. at an initial pressure of 4½ atmospheres. According to Stockalper and Schmidt, the loss of pressure in the pipes may be calculated by the formula—

$$z = \frac{785}{10^{10}} \times \frac{L}{d} p \left(5 \times \frac{1}{d}\right) v^2$$

wherein—L represents the length of pipe,

d the diameter of pipe,

v the velocity of air per second,

p the weight of unit volume of air at the pressure B and temperature t°,

z the loss of pressure, expressed in degrees water gauge.

The air velocity in the pipes should not exceed 10 metres per second. If V_0 be employed to express the volume of air that will pass through the pipes per second at the ordinary atmospheric pressure and at 0° C.; V the volume passing through at the temperature t° and the pressure B, then we have: $V = \frac{V_0}{B}(1 + 0{\cdot}003665t)$ and

$$v = \frac{V}{\frac{\pi d^2}{4}} = 1{\cdot}274 \frac{V}{d^2}, \quad \text{also } p = \frac{1{\cdot}293B}{1 + 0{\cdot}003665t}.$$

Efficiency of Compressed Air as a Motive Force.

134. If A be taken to express the work in horse-power done by a motor, then the efficiency of the air compressor is 0·75 A, less 6 per cent. for loss of pressure per 1000 metres of piping. Owing, however, to fluctuations of pressure, etc., the power generated in machines driven by compressed air is only about 42 per cent. of that furnished by the motor.

The cost of compressed air at 4½ atmospheres pressure is about ⅛ of a penny per cubic metre. At Saarbruecken the cost of compressing to 5½ atmospheres works out as low as 0·36 pfennig (0·0432 of a penny) per cubic metre.

UTILISING COMPRESSED AIR FOR VENTILATION.

135. The employment of compressed air for driving fans erected aboveground for the purpose of ventilating an entire pit or section of the workings is out of the question, it being undoubtedly far more economical to drive by steam engines direct. And even where there are several upcasts, situated at some distance apart and each provided with a fan, it is usually the practice to employ electricity in preference to compressed air as motive power, where there is a central boiler installation for generating power. On the other hand, compressed air is extremely useful in all cases of separate ventilation underground, the air being either used for actuating a motor or else direct on the ventilator. The former of these two systems is in general use in the Saarbruecken pits, the other in the Zwickau district of Saxony. In both centres it is a question of expelling firedamp from the working places; and consequently the ventilating current must act by pressure, in order to set up a vertical draught and properly mix and carry away with the fresh air, furnished through the tubbings, the firedamp which escapes from the face and collects more particularly at the roof.

When it is a question of affording separate ventilation to spots more than 200 metres away, a better plan is to erect special fans, communicating with the main ventilating current, and to blow air derived from the latter through tubbings into the place needing ventilation. If, however, separate ventilation is required in nearly all the preliminary works of an extensive pit,—as was the case at the Wilhelm shafts of the Oberhohndorf Colliery,—the erection of a large number of special fans and motors would be attended with considerable inconvenience and expense, since they would require to be continually shifted and re-erected as the work progressed. All this is obviated by adopting the method in use at Zwickau.

Experiments have been made on the possibility of ventilating by allowing the compressed air to escape from the pipe, through a small jet, discharging into the space to be ventilated. It is, however, clear that not only is there an entire loss of the work done in effecting the compression of the air, but also that the volume of air delivered in this manner is too small to be of use. According to measurements taken by von Steindel, the amount of air escaping through a circular orifice $1\frac{1}{2}$ millimetres in diameter, under a pressure of 3 atmospheres, is only 0·216 cubic metre per minute (at atmospheric pressure), and only 1·224 cubic metres through an orifice 5 millimetres in diameter; that is to say, a greatly insufficient amount in presence of firedamp.

136. A far better method of utilising compressed air is to allow it to escape through a Koerting injector, mounted in communication with the main ventilating current, and connected by tubbings with the spot to be ventilated. Such an injector, with an effluent orifice 1½ millimetres in diameter, and working under an air pressure of 3 atmospheres, will deliver 3·8 cubic metres of air per minute through a round tubbing, 10 metres in length and 15 centimetres in diameter, at a velocity of 217 metres. The injector thus increases 16·7-fold the amount of air conveyed to the face by the compressed-air pipe.

137. A still simpler and better method exists of utilising compressed air for separate ventilation. By fitting a small branch tube to the air main and allowing the compressed air to escape through a 1½ millimetre jet direct into the 2-inch tubbing, the delivery, at a working pressure of 3 atmospheres, is increased to 6·1 cubic metres at a velocity of 351 metres, *i.e.* 28·5 times as much as would be supplied by the compressed-air pipe itself. According as the diameter of the 10 metres of tubbing is varied between 15 and 31 centimetres (6 and 12 inches), and the jet between 1½ and 5 millimetres, so the spot to be ventilated can be supplied with 6·1 to 41·2 cubic metres of air, at a velocity of 351 to 550 metres. Under the same conditions, but with a tubbing 80 metres in length, the volume of air supplied would vary between 3·6 and 22 cubic metres at a velocity of 204 to 294 metres; with a 120-metre length of tubbing we should have 3·2 to 17·3 cubic metres of air at the velocity of 182 to 231 metres; and with 200 metres of tubbing, 2·2 to 13·7 cubic metres of air at an effluent velocity of 124 to 182 metres.

The arrangement of separate ventilation in a working section approached by an incline, and having to deal with a fiery seam, is shown in Fig. 72. Here the main air current is indicated by the arrows (——>—>), the compressed-air pipes by broken and dotted lines (—·—·—·), and the separate ventilating current set up in the tubbings by the aid of compressed air is shown by a broken line and small circle (O— — — — —).

As will be seen from the Figure, the main current from the drainage gallery is led through rising drives into the workings, and passes from the No. 6 gallery into the air way. The compressed-air pipes extend as far as the last upward drive in each working gallery, and at each of these spots is provided a compressed-air jet, which sets up a separate ventilating current that is led to the working place through a sheet-metal tubbing, and dissipates any firedamp found there. Given wide enough jets for the compressed air, and tubbings of sufficient size, it is possible in

certain cases to split a separate ventilating current and employ the same for ventilating two or more working places. See Figs. 73*a* and 73*b*.

Here two working galleries—one east, the other west—have been driven from the head of a double incline; and a separate ventilator for the incline has been set up in the drainage gallery. In the incline the round tinplate tubbing has a diameter of 31 centimetres (12 inches), and in each of the branching galleries it measures 21 centimetres (8¼ inches) (Fig. 73*a*). Then, according as the orifice of the jet at *a* measures 1½ to 5 millimetres, so the eastern gallery, which is 39 metres long, will receive 5·1 to 9·5 cubic metres of air at a velocity of 147 to 270 metres: whilst the western gallery, which is 20 metres long, receives 2·2 to 9·9 cubic metres at a velocity of 62 to 285 metres. The two galleries were afterwards extended and a rising drive made from each, so that four working places had to be ventilated. The tubbings were divided at the corners of the rising drives *c* and *d*, the air being conveyed to each of the working places through a length of 15-centimetre (6-inch) tubbing. With the lengths of gallery indicated in Fig. 73*b*, the amount of air delivered to the eastern rise (with the aforesaid jet orifices) ranged from 1·9 to 3·6 cubic metres, and in the gallery 2·1 to 3·7; in the western rise, 1·3 to 4·1 cubic metres, and in the gallery 0·9 to 3·8 cubic metres, at the velocities 111 to 204, 120 to 209, 73 to 233, and 53 to 216 metres respectively, measured on issuing from the tubbings.

138. It will be evident from these figures that the effluent velocity of the air at the end of the tubbings is still very considerable in part, and that consequently a good deal of the tension of the air is wasted even in this method of ventilation. On the other hand, it is alleged by von Steindel as an advantage that the method can also be usefully employed on the occurrence of an outbreak of fire in the pit. To prevent hindrance arising from the presence of smoke and poisonous gases when working near the seat of a pit fire, it is necessary to have a supply of fresh air coming from the rear, without this supply being so great as to fan the conflagration. If it be feasible to advance the tubbings as far as the seat of the fire, and then set up a back draught with compressed air in a tubbing, so as to produce an effect of suction in the latter, there is then a possibility of removing large volumes of foul air from the locality of the fire, whilst the fresh air extends slowly back along the gallery. The degree of ventilation can be suitably regulated by using larger or smaller jets.

SEPARATE VENTILATION BY COMPRESSED AIR MOTORS AND FANS.

139. According to Uthemann, the ventilation of blind headings, such as incomplete cross drivages, drainage galleries, air ways, inclines, etc., which are only in communication with the main ventilating current at one end, is effected in the Saarbruecken district, chiefly by means of motors worked by compressed air or hydraulic power, which motors drive small Ser fans deriving air from the main current and forcing it through tinplate tubbings to the working places. As already mentioned, this method is found necessary to ensure the thorough admixture of the air and firedamp. In the district in question the practice of ventilating with parallel air ways or brattices has been entirely abandoned for such blind galleries, having been found more expensive than the compressed-air method.

Uthemann starts with the generally applicable assumption that, in order to ascertain the power required to keep the total air current in motion, the necessary depression h_1, for securing the ventilation of the blind heading, must be added to that needed to move the main air current. Thus, for example, if it be considered undesirable to charge the main current with the task of moving a split current, a separate source of power must be provided for the latter purpose. The question as to whether, in any special case, the ventilation of a portion of the pit is best effected from the main current or by separate means, will be discussed later on in dealing with the theory of individual temperament (modulus) of various sections of the workings. At the Reden pit, Saarbruecken, Ser fans, with a diameter of 20 to 27 inches (made by G. Pinette of Chalons), have been found to answer very well. (A larger fan of this type will be described later on.) The fan is driven by a small vertical engine, with $3\frac{1}{2}$-inch cylinder and $3\frac{1}{8}$-inch stroke, and the belt pulley gear is speeded up so that the fan makes four times as many revolutions as the engine. The speed of the fan can also be easily changed from 200 to 1000 revolutions per minute. An apparatus of this kind, which does not occupy more than 4 feet of space in any direction, can be run continuously for years, without any great outlay for repairs, and only costs about £45 in the first place.

We shall revert to the technical results obtained by this method, after dealing with hydraulic arrangements for separate ventilation. Mention has already been made of the provision of hydraulic mains in the workings of pits suffering from firedamp and large accumulations of inflammable coal dust. In these places occasion is therefore afforded for employing the water for the purposes of separate ventilation, as has been done, for instance, at the Koenig pit, Saarbruecken.

Hydraulic Separate Ventilation.

140. Fig. 74 represents a Koerting jet, with inside screw joint, for spraying water from hydraulic mains, for the purpose of drawing air from the main current and forcing the same through the tubbing L (Fig. 75). In this latter illustration S represents the suction pipe, which takes air from the main current; J is the branch from the hydraulic main, and H the tap for closing same. Inside the tubbing, and below H, is the jet which forces the sprayed water and indrawn air through the tubbing L. The widened pipe V, between the jet and the tubbing L, serves for the separation and collection of the water spray, which is then run off through a syphon without any waste of air.

The following table gives particulars of different sizes of Koerting spray jets, with their capacity:—

No. of Jet.	Width of Tubbing.	Diameter of Jet Orifice.	Capacity per Hour at a Working Pressure of 6 Atmospheres.
	Millimetres.	Millimetres.	Cubic Metres.
1	150	13	250
2	200	13	500
3	300	20	1000
4	400	25	1500

By means of a similar apparatus at the Melchior pit, Waldenburg (Lower Silesia), 1250 cubic metres of air per minute were delivered to the working face through 380 metres of tubbing, with a consumption of 5·666 cubic metres of water per hour; and 1710 cubic metres of air, with 8·136 cubic metres of water per hour.

For shorter distances, up to 200 to 300 metres, the water-spray method is successfully employed at the Koenig pit, Saarbruecken, the jets used having orifices only 3 to 4 millimetres in diameter, and costing 15s. apiece.

For greater distances, however, in the same pit, preference is given to Pinette Ser fans, driven by Pelton water-wheels, 300 millimetres (12 inches) in diameter, and running at a speed of 1700 revolutions per minute, with a working pressure of 11 to 18 atmospheres in the water main. The fans are fitted with stepped pulleys, and run at speeds ranging from 750 to 1000 revolutions. The Pelton wheels, made by the Deutscher Wasserwerks-gesellschaft, of Hoechst-on-Rhine, cost £20, or £60 with the Ser fan.

A very important matter in separate ventilation is the good construction, proper dimensions, and suitable jointing of the tubbing. The best material for the purpose is 1½ to 2 millimetres galvanised iron. For ordinary conditions 13¾-inch tubbing, with socket joints, or 12-inch

tubbing with Wirtz patent connections, will suffice. The Wirtz joint consists of an elastic iron band, which is lined with canvas, and is fastened with a wedge round the flush-butted ends of the pipe. It enables the tubbing to be assembled and taken down quickly, facilitates rounding curves, and makes a tighter joint than sockets. With tubbing of this kind, 15 cubic metres of air can be delivered to a working place a distance of 300 metres. The loss of air amounts to 25 per cent. in a distance of 100 metres, 65 per cent. in 300 metres, 74 per cent. in 400 metres, and 76 per cent. in 500 metres.

Where the galleries are over 300 metres long, it is advisable to use 15¾-inch tubbings with flange joints. These pipes are fitted at the ends with turned and riveted flanges, like those on wrought-iron steam pipes, and are tightened up by bolting loose outer flanges after the insertion of rubber washers. In this case the loss of air is small, and does not attain 10 per cent. in a distance of 565 metres.

For passing round curves, special pieces bent to the sector of a circle should be used—not angle pieces!

At the Reden Colliery 18 fans, worked by compressed air, are in use for the separate ventilation of 23 working places; and at the Koenig pit 30 working places are separately ventilated by means of 14 hydraulic fans and 12 water-jets. The fans are run at an average speed of 375 revolutions per minute, and the average length of the tubbings is 165 metres. The highest speed is 820 revolutions. The mean air supply at the face is 17·5 cubic metres per minute, or 4·2 cubic centimetres per man.

Working Expenses of Separate Ventilation.

141. The annual cost of compressing the air (to 5½ atmospheres pressure) for driving a Ser fan delivering 17·5 cubic metres of air to the working place, at the Reden pit, is £34, 10s. (1 cubic metre costs, in fuel, wages, and upkeep, 0·0324d., plus 10 per cent. of the cost price of the compressor, 90s., and £5 for maintenance, lubrication, and attendance, making altogether £44).

If the annual rate of advance in the working places be taken as 200 to 600 metres, then separate ventilation costs 1·5s. to 4·4s. per metre. To this must be added 20 per cent. written off the prime cost of the patent tubbings, 11d. per metre, thus bringing up the cost to 2·4s. to 5·3s. per metre—an average of 4s. (Bratticing would cost 10s., and parallel headings 10s. to 30s. per metre.) The annual working expenses per Ser wheel, driven by a Pelton water-wheel, at the Koenig

pit, amount to 92s., which, together with 10 per cent. for depreciation (120s.), and 100s. for upkeep, makes a total of 312s.

The water-jet apparatus costs 110s. per annum for upkeep, the cost of 1 cubic metre of water under a pressure of 11 to 18 atmospheres being taken as 0·216d. To this must be added 10s. for wear and tear of the tubbing, making together 120s. The hydraulic system is therefore the cheaper, the cost per running metre of heading being only 2s., including an allowance for the wear and tear of the tubbings.

The following results were furnished by a Ser fan, used in conjunction with 12-inch iron tubbings :—

Length of Tubbing.	Revolutions per Minute.	Volume of Air per Minute.	Loss of Air in Tubbings.
Metres.		Cubic Metres.	Per cent.
110	798	31·67	27
110	1063	39·33	25
210	763	20·87	50·5
210	970	26·27	50·0
410	698	10·25	74·5
410	928	12·50	74·5
510	685	9·84	75·0
510	907	11·55	77·0

According to Mayer, a Capell fan, worked by air supplied from a Dinnendahl compressor, was used in driving headings, of a total length of 555 metres, at the Heinrich shaft of the Kaiser Ferdinand-Nordbahn Colliery, Maehrisch-Ostrau. The dimensions of the fan were: diameter of vanes 430 millimetres, width 160 millimetres; diameter of air compressor cylinder 80 millimetres, stroke 60 millimetres. Twelve-inch smooth, well-jointed tubbings were used for conveying the air.

Result of Observations at the Heinrich Shaft.

Length of Tubbing.	Speed.	Volume of Air supplied.	Air Pressure.
Metres.	Revolutions.	Cubic Metres.	Millimetre Water Gauge.
103	400	11580	3
103	600	16164	4·5
103	1000	27912	9·26
203	400	9546	4·75
203	600	14124	8·50
203	1000	23796	18·0
303	400	7044	5·25
303	600	11874	9·25
303	1000	20154	23·25
403	400	6276	5·75
403	600	8868	9·75
403	1000	14208	25·50
555	600	6012	12·75
555	1000	9342	27·00

The fan actually ran at an initial speed of 400 to 500 revolutions, afterwards 800 to 1000, and finally 1100 revolutions per minute.

The expenses were high, and repairs frequent. A jet with 3 millimetres orifice was employed in aid, but the efficiency was 20 per cent. lower, and the consumption of air greater, than with the fan. The observer in this case apparently did not regard separate ventilation by compressed air with such favourable eyes as the recorder of the Saarbruecken experiments.

Separate Ventilation by a Direct Fall of Water—Water Drums.

142. A ventilating apparatus long used in mining is the water drum (Fig. 76), wherein the force of falling water is utilised direct for the compression of air. The air drawn downwards by the water passes through a descending pipe *c* into a compression chamber *a*, and discharges through a conduit *b*. The compression chamber *a*, which is open at the bottom, stands in a larger and higher water chest *d*, which is open at the top, over the edge of which flows the water delivered through the intake pipe *c*. The difference of level of the water in the inner and outer vessels *a* and *d* is a measure of the pressure produced in the vessel *a*. As the water descends the intake pipe *c*, it draws air in through the orifices *xx*. As, however, only about 8 to 15 per cent. of the total force developed by the water is utilised in this apparatus, it follows that the same is only suitable for temporary use in the ventilation of a shaft or heading, any form of motor (Pelton wheel) and fan being otherwise preferable.

Electricity as a Motive Power in Ventilation.

143. Mention has already been made of the feasibility of employing electricity, generated at a central station above bank, for driving fans in shafts at a distance. With equal ease the same power can be employed for driving underground fans from dynamos situated at the surface, electricity constituting the most convenient and best means of transmitting power to great distances without much loss. When, as is frequently the case in hilly mining districts, a natural fall of water is available in the vicinity of the mine, the same can be utilised for the purposes of ventilation. The theoretical energy N, furnished by falling water, can be expressed by the formula $N - 13{\cdot}33$ QH horsepower, wherein Q represents the volume of falling water in cubic metres per second, and H the height of fall in metres.

The mean volume of water must be determined from the maximum and minimum quantities, and, in addition, it is necessary to ascertain the height of fall, the length and width of the supply conduit or pipe, and the maximum output required from the dynamo machine.

For a height of fall up to 25 to 30 metres, turbines may be used: beyond these distances the Pelton wheel will be found best, being specially adapted for driving dynamos by reason of its high speed. The following data are applicable to Pelton wheels:—

Height of Fall.		Energy developed in Horse-Power with a Wheel Diameter of			
Metres.	Feet.	90 centimetres (35½ inches).	120 centimetres (47½ inches).	150 centimetres (59 inches).	180 centimetres (71 inches).
30	98	16	30	46	67
60	197	47	85	132	190
90	295	87	156	244	350
120	394	135	240	375	540
180	590	245	440	689	990
250	820	380	675	1060	1525
300	984	530	940	1480	2130
Weight of wheel, lbs.		860–992	992–1410	1410–2095	2095–3196

For the electrical transmission of power the following installation is required:—

(1) A source of power, which may be either a steam engine, gas engine, hydraulic motor, etc.

(2) A primary dynamo for the conversion of the mechanical power of the prime motor into electrical energy.

(3) A secondary dynamo (motor), which receives the electric current and reconverts its energy into mechanical work.

(4) A (usually double) conducting wire, connecting the two dynamos.

The useful energy developed at the shaft of the secondary dynamo is found by experience to be equal to the output of the prime motor, after deduction of the losses of current, and by friction, in the line wire and the two dynamos. The total loss may be estimated in general as 25 per cent., so that 75 per cent. of the original energy is recovered as the nett efficiency of the installation.

If the distance between the two dynamos be expressed by l, the total length of line wire will be $2\,l$ when a return wire is used. Further, if N be employed to indicate the horse-power effect of the secondary dynamo (motor), E the tension of the current, in volts, at the terminals of the motor, a the mechanical efficiency of the motor dynamo (usually 90 per cent.), and S the sectional area of the line wire in square millimetres, then the output of the electro-motor will be $EJ = 736\frac{N}{a}$ watts.

One electrical horse-power is equivalent of 736 watts, and 1 watt is 1 volt multiplied by 1 ampere (V × A).

V being the loss of tension in the line wire, the resistance of which is expressed by R, we then have $V = RJ$ volts, wherein J expresses the intensity of the current in amperes.

To ascertain the value of R, use is made of the formula $R\frac{2lm}{S}$, wherein m is the resistance of a copper wire 1 metre in length and 1 square millimetre in sectional area. For copper, the value of m is given as 0·017.

Then, in order to ascertain the sectional area of the conducting wire for a new installation, the following formula is called in aid—

$$S = \frac{25{\cdot}024 \times N \times l}{E \times a \times v} \text{ square millimetres.}$$

Example.—Supposing the problem to be the sectional area of a copper wire S for conveying 10 horse-power in such a manner that the effective energy of 10 horse-power shall be developed in an electromotor driving a fan situated at a distance of 1500 metres from the prime motor. The tension of the current is assumed as 400 volts, the loss of tension in the line wire not to exceed 10 per cent., and the mechanical efficiency of the electro-motor as 90 per cent.

$$\begin{aligned} \text{In this case } N &= 10 \text{ horse-power.} \\ l &= 1500 \text{ metres.} \\ E &= 400 \text{ volts.} \\ a &= 0{\cdot}9. \\ V &= \text{volts.} \end{aligned}$$

$$\text{Consequently } S = \frac{25{\cdot}024 \times 10 \times 1500}{400 \times 0{\cdot}9 \times 40} = 26{\cdot}066 \text{ square millimetres.}$$

Hence the diameter of the line wire d will be—

$$d = \sqrt{\frac{26{\cdot}066}{0{\cdot}785}} = 5{\cdot}7 \text{ millimetres.}$$

Therefore, given an efficiency of 75 per cent., the prime motor must develop a useful effect of $10 \div 0{\cdot}75 = 13{\cdot}33$ horse-power.

Motor-driven Ventilating Appliances generating an Air Current in the Pit.

144. The mechanical appliances for producing a ventilating current may be divided into two main classes. The first of these is characterised by the formation of an enclosed hollow space, which increases in dimensions at first and then decreases, air being drawn in during the first stage,

and then compressed and expelled during the second stage. This class of apparatus evidently resembles a pump, and is adapted for dealing with small definite volumes of air under high tension. This latter feature, however, is by no means a desirable or favourable circumstance in pit ventilation, the matter in hand being rather the propulsion of a large volume of air.

The appliances of the second class comprise fans of the screw type and centrifugal fans. The former act by the rotation of certain slant or screw-like surfaces, which propel the air in the same manner as substances are transported by a worm conveyor; whereas the centrifugal fans are fitted with vanes, by means of which the air is drawn in at the axis of the fan and expelled at the periphery. Both kinds furnish a continuous current of air, and are distinguished by the peculiarity that the working parts do not separate those parts of the pit whence the air is drawn, from the atmospheric air into which the air current is discharged. This is, of course, an advantage, from the fact that, in the event of the stoppage of the fan, the air current, though weakened, is not entirely interrupted.

The ventilating appliances of the first-named class are, fundamentally, apparatus for measuring the air to be propelled; they work intermittently, do not produce any continuous uniform air current, and, furthermore, they entirely close the communication between the pit workings and the outer air, so long as they are at a standstill. Their dimensions must be selected in accordance with the purpose in view and the effect to be produced, and may therefore occasionally have to be projected on gigantic lines. For this reason, it is a matter of small wonder that the use of such appliances has entirely lost its popularity, and that only a few, already existing, are now in work.

On the other hand, in the case of fans, there is no strict relation between their dimensions and the volume of air to be propelled, the ratio being capable of modification within wide limits; and small fans may be used to deal with large volumes of air, by running them at high speed or velocity. This forms another advantage of this class of ventilator: nevertheless, no definite decision has yet been formed by practical men as to whether it is preferable to work with large heavy fans run at slow speeds, or with quick-running fans of smaller dimensions and less weight. In the meantime, it is therefore advisable to adopt a medium course. It may, however, be mentioned that the attempts to employ fans of the screw-propeller type in place of centrifugal fans have not proved successful, their inferior efficiency having led to their being discarded.

CHAPTER VII.

VENTILATORS AND FANS.

VENTILATING machines with variable internal capacity, and working by the rectilinear movement of a bell or plunger.

145. THE HARZ VENTILATOR (Fig. 77).

The Harz ventilator is a machine that has long been used in the Harz mountain ore mines. It consists of a fixed chest K of circular section (seldom rectangular), open at the top, and traversed at the bottom by an air pipe t, communicating with the workings to be ventilated. The mouth of the pipe t is fitted with a suction valve c, opening upwards. The vessel P is partly filled with water to form a seal, and into this dips a bell B which can be raised and lowered by a piece of mechanism T, which is usually a pump rod. The bell is open below, and is provided in the top with a second valve c^1, also opening upwards. When the bell is raised the rarefaction of the air inside causes the valve c to open, c^1 remaining closed, and air flows upwards through the pipe t. On the descent of the bell the air underneath is compressed, closing the valve c, whilst c^1 is forced open and allows the imprisoned air to escape. In the position shown in Fig. 77 the arrangement of the valves is such that the apparatus acts by suction, but it may be easily modified so as to work by propulsion. Fairly high pressures can be obtained with this apparatus, and a considerable pit resistance can be overcome; consequently it may be used for ventilating long cross drivages, drainage galleries, etc.—a circumstance indicating its employment in cases where compressed air, hydraulic power, or some other cheap source of motive power, is not available. However, the volume of air supplied by this apparatus is somewhat limited, since the bell can scarcely exceed 40 inches in diameter, the stroke 80 inches, or the speed 5 to 6 strokes per minute.

Other Forms of Plunger and Bell Apparatus.

146. All other forms of similar ventilators—such as were chiefly used in English and Belgian mines—are now merely of historical interest, it being improbable that the principles on which they were based will be utilised again in connection with mine ventilation. These apparatus resembled the blowers used in blast furnace work, or the Harz ventilator described above.

Fig. 78 (Plate XII.) represents the old vertical plunger ventilator, formerly used at the Bonne Esperance Pit, Seraing.

Fig. 79 is a horizontal Mahaut ventilator, such as was formerly in use at a Charleroi colliery.

Fig. 80 is a vertical ventilator at Grand Buisson.

Fig. 81 is a Deschamps plunger ventilator.

Fig. 82 is a Nixon ventilator.

Fig. 83 is a Struve bell ventilator, and Fig. 84 a De Vaux machine. (These illustrations are taken partly from von Hauer's work on mine ventilation, and partly from Guibal's treatise on the same subject.)

Rotary Ventilators with Variable Internal Capacity.

The Fabry Fan.

147. Among apparatus of this type, the Fabry fan was at one time extensively used in Westphalian and Belgian pits, but is hardly to be found in work anywhere at present. It was constructed on the basis of the pump invented by Murdoch (foreman in Watt's works). See Fig. 85.

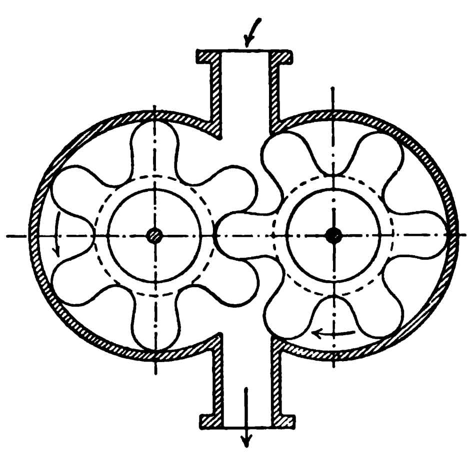

Fig. 85.

The mechanism consists of two 6-toothed wheels of equal dimensions, arranged side by side in a closed case. The teeth engaged with one another, and their extremities also came into contact with the inner walls of the case, which latter was provided with an intake and outlet, situated above and below respectively. The wheels were set in rotation from outside the case, and, in revolving, air was drawn into the spaces

between the teeth, and expelled on the farther side. The action could be reversed by turning the wheels backwards. The efficiency of the apparatus as a ventilator was, however, low, owing to the fact that no air-tight contact was secured between the two sets of teeth or between the latter and the walls of the case, and also on account of the great friction. In the Fabry fan the corresponding wheels had only three teeth each, and the clearances were not increased in proportion to the larger dimensions of the apparatus. This fan, which is illustrated in Fig. 86 (Plate XIV.), consisted of two wheels, each carrying three epicycloidal cross-shaped teeth or arms, so arranged that one tooth of the one wheel made contact with two teeth on the other, and prevented any escape of air between them. The teeth also fitted air-tight against the sides of the case. Air was drawn in through a suction pipe *s*, connected with the case, and was discharged into the open air at the top. Usually the case consisted of a cast-iron top resting on a lower part of masonry, or else entirely made of brickwork.

Calculating the Volume of Air propelled by the Fabry Fan.

In calculating the volume of air propelled by a single revolution of this fan, we must commence at the position shown in Fig. 87, where the tooth of the left-hand wheel O_1 is horizontal, and the cross qp is just making contact with the top of tooth B at c, whilst contact is ceasing between the lower arm of the cross and the tooth C at d.

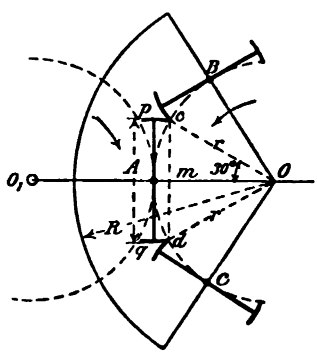

FIG. 87.

The space enclosed by the three teeth B, A, and C is the air chamber, the charge of air in which is returned to the suction chamber, and consequently must be deducted from the total capacity of the fan. The capacity of the space OBAC has therefore to be determined. By connecting c with d, p with q, and c and d with O, we have the angle $cOA = 30°$, since the angle $AOB = 60° = 2cOA$.

The space $OcpqdO$ consists of the triangle Ocd and the rectangle $cpqd$. Om is $= r \cos 30° = r0{\cdot}866$ $Am = r \times r \cos 30° = r\,(1 - 0{\cdot}866) = r0{\cdot}134$.

The triangle $Ocd = \dfrac{c \times d \times Om}{2} = \dfrac{r \times r \times 0 \times 866}{2} = r^2 0{\cdot}433$. The rectangle $cpqd = r \times Am = r \times r0{\cdot}134 = 0{\cdot}134r^2$. Consequently the triangle $Ocd + cpqd = r^2 0{\cdot}433 + 0{\cdot}134r^2 = 0{\cdot}567r^2$. For an entire revolution

of the wheel, the capacity of the space $OcpqdO$ must be multiplied by $6 = 6 \times 0{\cdot}567r^2$. The capacity of the space discharging the air into the atmosphere is equivalent to $R^2 3{\cdot}1415$, multiplied by the breadth L of the wheel (R representing the radius of the toothed wheel). Hence, there being two wheels, the theoretical volume of air discharged at each revolution is $= 2L(3{\cdot}1415R^2 - 3{\cdot}402r^2)$.

The usual distance between centres of the wheels of the Fabry fan was 2 metres (80 inches), the radius of the circle of contact 1 metre, and the radius of the case 1·7 metre. In such event, the volume of air expelled at each revolution = 22·6 cubic metres.

A fan of this kind, to discharge 20 cubic metres of air per second, must be run at a speed of 60 revolutions per minute; but the practical limit of speed was found to be 30 revolutions. Attempts were made to construct fans of larger size, but the maximum output attained never exceeded 35 cubic metres per revolution, or 10 to 11 cubic metres per second. A fan of this capacity consumed 12 to 15 horse-power, and cost £700 to £800, including motor and enclosure, but exclusive of boiler.

Defects of the Fabry Fan.

It was found impossible to increase the dimensions of the Fabry fan beyond the above limits, owing to the difficulty of securing effectual contact between the two wheels and proper air-tight connection of the parts. The excessive superficial dimensions of larger wheels also induced bending and distortion, owing to the excessive difference of density between the inner and outer air, the consequence being either too much or too little play for the surfaces of the teeth, resulting in mutual pressure and breakages.

It was, moreover, found impossible to increase the volume of air in case of need, by running at higher speed, since the difference in the pressure of the inner and outer air then set up vibration in the arms and induced breakages. The Fabry fan is reversible, *i.e.* may work by suction or propulsion. Experience shows that, under certain circumstances, this is a valuable property; nevertheless, this reversal was found impossible in practice, being beyond the strength of the machine. Attempts made to improve the fitting of the contact surfaces, by the aid of leather, rubber, etc., proved a failure, it being quickly found that the same resulted in excessive friction and loss of power. A by no means inconsiderable loss of power also resulted from the high effluent velocity of the discharged air. Again, inconvenience arose through the necessary play of the outside driving cogs failing to properly correspond

with the movement of the interior arms. Finally, as in all similar appliances, the Fabry fan was attended by the defect that, in the event of a stoppage, the communication between the pit and the outer air was entirely interrupted, and ventilation completely prevented.

Superficially examined, the Fabry fan would appear to be a remarkable invention, but its numerous defects made it a very imperfect ventilator, and an improved form of construction therefore became indispensable, more particularly in view of the increasing necessity for the provision of larger volumes of air for the ventilation of the pit.

The Roots Blower.

148. Another enclosed blower, which came into the field towards the end of the 'sixties, was that of Roots (Fig. 88, Plate XIV.).

This consists of two arms shaped like the figure 8, covered with soft wood, and mounted on two parallel shafts in a cast-iron case, which arms rotated in the direction of the arrow (see Fig. 88) and drew in air through the lower aperture, to expel it at the top. The shafts are fitted, outside the case, with cog-wheels of equal size, driven by belt pulleys. The surfaces of contact between the periphery and ends of the arms and the case must be coated with a semi-solid lubricant of tallow and wax, partly to reduce friction and partly to prevent excessive back flow of air.

Roots blowers were first used in smelting works, for supplying air to forges, cupola furnaces, Bessemer convertors, etc., afterwards also for separate ventilation in mines, and finally for ventilating the entire workings in many collieries, especially in America and England. One instance of their use for this purpose is also afforded at Mansfeld (Germany). By means of this class of blower it is easy to overcome resistances of 200 to 300 millimetres water gauge. As, however, 80 to 100 millimetres are already a high figure for pit resistances, it may be concluded that Roots blowers are not specially adapted for the main ventilation of mines. Difficulties are also encountered in connection with the lubrication and close fitting of the vanes, both with regard to one another and the sides of the case, in large blowers, temperature also constituting a factor here. The replenishing of the lubricant also gives rise to stoppages, etc.; so that, all things taken into consideration, the Roots blower is hardly able to compete with the centrifugal fan as a means of effecting the main ventilation of pits, especially as the stoppage of the blower entails an entire cessation of ventilation. The blower is more likely to be useful for separate ventilation in cases where high

resistance has to be overcome, such as in long cross drivages, drainage galleries, etc.

The following particulars may be given of the most important constructive details of the Roots blower. If the longer axis Af of one of the vanes (Fig. 88) be taken as 7, then the radius at the centre CO will be $=\frac{1}{14}$. The radius E of a contact circle T or T_1, and the outer toothed wheels, may be set down as 2, and the radius r of the periphery of the head and the recessed circle will be 1·5 (or, more accurately, 1·52). A right angle is enclosed by the lines Oa^1 and Od, as also by O^1a and $O^1b = E$. The radius R of a vane AO or BO^1 is 3·5.

The theoretical volume of air expelled by a single revolution of this fan may be expressed by q, which is found by quadrupling the product of the shaded area F_1 (Fig. 88), multiplied on the axial length l of the vane. Hence $q = 4F \times 1$ cubic metre.

$F = R^2\frac{\pi}{2} - 2{\cdot}571r^2 - E^2$. Consequently—

$$q = 4\left(R^2\frac{\pi}{2} - 2{\cdot}571r^2 - E^2\right)l.$$

If the values r and h be substituted for R and E, wherein $R = \frac{h}{2}$, $r = \frac{h}{4{\cdot}667}$, and $E = \frac{h}{3{\cdot}5}$, then: $q = 4\left(h^2\frac{\pi}{8} - \frac{2{\cdot}571h^2}{4{\cdot}667^2} - \frac{h^2}{3{\cdot}5^2}\right)l$, and, assuming $l = 2h$, $q = 8h\left(h^2\frac{\pi}{8} - \frac{8h^2}{5}\right) = h^3\left(\pi - \frac{8}{5}\right)$, or $h = \sqrt[3]{\frac{q}{1{\cdot}54}} = 0{\cdot}866\sqrt[3]{q}$ cubic metres.

The entire breadth, $b = Af$, of the case is: $b = \left(7 + \frac{1}{14} + \frac{7}{2}\right)h$, or $b = \frac{22}{14}h$. To this must be added the necessary free space for play between the teeth of the wheels, and between the latter and the case, an allowance of 2 to 5 millimetres being made for each of these three contingencies, according to the size of the blower.

The speed of the Roots blower is 250 to 500 revolutions per minute, according to the size, the larger machines of course running more slowly than the smaller ones.

Example.—Take the case where 20 cubic metres of air per minute are to be supplied to a separately ventilated working place by means of a Roots blower running at 300 revolutions per minute, the efficiency of the blower being assumed as 85 per cent. The problem is to determine the

size of the fans and the strength of the motor when the pit resistance is 17 millimetres water gauge.

If $Q_1 = 20$ cubic metres per minute, then the volume of air per second will be $Q = 20 \div 60 = \frac{1}{3}$ cubic metre.

The speed of the blower is 300 revolutions per minute, *i.e.* 5 revolutions per second. Hence the volume of air to be supplied by the blower per second will be: $q = \dfrac{\frac{1}{3}}{0{\cdot}85 \times 5} = 0{\cdot}07843$ cubic metre.

Consequently: $h = 0{\cdot}866\sqrt{0{\cdot}07843} = 370{\cdot}7$, or, in round numbers, 371 millimetres.

The breadth will be: $b = \frac{22}{14} \times 371 + 3 \times 2$ millimetres $= 583$ millimetres.

The length l of the case will be $= 2 \times 371 = 742$ millimetres, to which must be added 2 millimetres for play on either side.

The motive power required to propel $5 \times 0{\cdot}07843 = 0{\cdot}39215$, or, in round numbers, 0·4 cubic metre of air per second, at 17 millimetres water gauge pressure, will be—

$$N = \frac{Q \times h}{75} = \frac{0{\cdot}4 \times 17}{75} = 0{\cdot}09 \text{ horse-power, } i.e. \text{ insignificantly small.}$$

Of course, no allowance has been made in this calculation for the friction in the journals, the contact of the two vanes with each other or the case, or for the friction of the outer cogs and the belting.

In comparison with the air resistance, however, these resistances must be somewhat high, since, according to Uhland's *Engineers' Calendar*, 3 horse-power is required to drive a Roots blower to furnish 21 cubic metres of air per minute for a smithy forge. Since, for this class of fire, an air pressure of 250 millimetres water gauge should be more than sufficient, the propulsion of 0·4 cubic metre of air per second would require $N = \frac{0{\cdot}4 \times 250}{75}$ 1·33 horse-power. Hence $3 - 1{\cdot}33 = 1{\cdot}66$ horse-power will be required to overcome the resistance due to friction.

This amount will, however, be only slightly lower in the case now under consideration (air resistance = 17 millimetres water gauge), and may therefore be set down as 1·5 horse-power, hardly less.

This example shows the great waste of power involved in the use of the Roots blower for separate ventilation, and the superiority of centrifugal fans (Ser, Pinette fans) for this purpose, as was proved by the experience gained in Saarbruecken.

THE LEMIELLE VENTILATOR (Figs. 89*a* and 89*b*, Plate XIV.).

149. About the middle of last century the Lemielle ventilator was in very extensive use for main ventilation in Belgian collieries, owing to the absence of better appliances at that time. Various modifications were made from time to time, but in the main the apparatus consisted, as shown in Figs. 89*a* and 89*b*, of a hexagonal or cylindrical drum t, mounted on vertical journals a, n, and revolving within a brickwork enclosure B. Equidistant on the drum t were mounted three vanes, f, f^1, f^2, hinged at both ends, which by opening and closing made contact with the inner surface of B, and thus divided the chamber into three compartments, *I*, *II*, *III*, during the rotation of the drum. The continual pressure of the outer ends of the vanes against the wall of B was secured by connecting rods l, l_1, l_2, articulated both to the vanes themselves and to a crank shaft C. Two apertures S and T, equal in height to the drum t, were provided in the walls of B, the one, S, communicating with the pit by a conduit, and serving as intake, whilst the other, T, conducted the expelled air into the external atmosphere.

The chamber B was closed top and bottom by plane surfaces.

The drum t was set in rotation by a steam engine, mounted above the chamber B, the upper rosette A of the drum being keyed on to the upper journal n, whilst the lower one, A^1, ran loose on a.

For the reception of the connecting rods l, l_1, l_2, slots are cut in the cover of the drum, and are packed with split strips of leather, between which the rods move to and fro without allowing any escape of air. According to the ground plan (Fig. 89*b*), three compartments, *I*, *II*, and *III*, are formed in the chamber during the rotation of the drum t. The air in *II* is forced out through the aperture T, whilst that in the compartment *III* is conducted to the intake.

In English pits the Lemielle ventilator was constructed of very large dimensions, the chamber B measuring up to 11½ feet radius and 33 feet in height. The ventilating efficiency is stated to be 0·7 to 0·84 of the theoretical value, and the mechanical efficiency 0·5 to 0·6 ; nevertheless, the apparatus is hampered by such serious defects that nowadays no one would think of using it. The upkeep and lubrication are troublesome and expensive. Owing to the fact that the crank axle C could only be properly supported at the bottom, and was merely guided in an imperfect manner by the shaft n of the crank at the top, lateral displacements resulted, the consequence being elongation of the rods l, jamming of the vanes f, and breakages of the whole apparatus. These

dangers became more imminent the larger the machine and the higher the working speed.

Numerous other ventilators belonging to the same main type have been constructed and tried; but, as they are mostly still less satisfactory than those described, they need not be further considered here.

Fans of the Screw-Propeller Type.

150. There is another class of fan that has proved unable to make headway in practical mine ventilation, namely, fans of the screw-propeller type. (See Figs. 92*a* and 92*b*.) Though the friction of the working parts and internal resistance of the air in these are very small, and their capacity is large,—a favourable circumstance for mine ventilation,—nevertheless, like the ventilating furnace, they are unable to produce more than a slight degree of depression, and cannot overcome pit resistances exceeding 20 to 25 millimetres water gauge. Such fans are suitable for the ventilation of rooms, factories, etc. (because in these cases there is no great resistance to overcome), but not for pit work. Moreover, their useful effect is very low, scarcely attaining 20 to 25 per cent., and declining very rapidly on an increase in the resistance.

Mention may be made here of the fans of Lesoinne (Figs. 90*a* and 90*b*), Motte (Fig. 91), and Pasquet, which is very similar to that of Motte.

According to Ponson, a Lesoinne fan was set up at the Grand Bac pit, Liège, in 1845. It consisted of six flat vanes, 2·66 metres in diameter, set aslant on a vertical axis, and overlapping near the centre, but leaving a certain free space between each pair at the periphery. The fan was run at a speed of 200 revolutions per minute, produced a depression of 13 millimetres, and delivered 9·12 cubic metres of air per second. The cost was £140.

The Motte fan at Sauwartan-sur-Dour measured 1·4 metres in diameter, ran at a speed of 400 to 500 revolutions per minute, produced a depression of 20 to 25 millimetres, furnished 3 to 4 cubic metres of air per second, and cost about £240.

Just as insufficient for meeting present-day requirements as the two foregoing was the Pasquet fan erected at the Ardinoise pit.

Centrifugal Fans.

151. The employment in mines of small centrifugal fans, of the kind shown in Figs. 93*a* and 93*b*, is an old practice, Agricola having referred

to their frequent use in the Freiburg ore mines early in the seventeenth century. Similar fans of wood have also long been used by agriculturists, under the name of winnowing fans, for cleaning corn.

Hand-power Ventilating Fan.

In its oldest and simplest form the centrifugal fan consisted of a horizontal shaft carrying four straight vanes, and set in motion by a hand crank. The vanes were enclosed in a circular case with flat sides, and an effluent orifice at the periphery. The air was drawn in through lateral apertures surrounding the shaft, and was expelled through the peripheral orifice by the centrifugal force generated by the rotation of the fan; hence the name centrifugal fan. From this hand fan have been evolved the various fans now used in mine ventilation, whether for supplying air to a portion or the whole of the workings.

The principal part in the introduction of the centrifugal fan, both as regards the development of the fundamental principles and their practical application, has been played by Belgium, for the simple reason that the abundance of firedamp in Belgian mines, and the progressive extension of mining operations to continually increasing depths, rendered the perfection of the ventilating appliances an indispensable necessity. It should also be mentioned that, thanks to the forethought of the State, technical education and engineering have been very thoroughly fostered in that country.

The Letoret Fan (Figs. 94*a* and 94*b*, Plate XV.).

152. Letoret, formerly principal of the Mons School of Mines, was the first to recommend the application of centrifugal fans for mine ventilation, at the time when Combes published his researches on ventilating appliances. The Letoret fan was installed at the St. Victoire pit, Agrappe. It consisted of four vanes m (Figs. 94*a* and 94*b*), mounted at right angles on the horizontal shaft a. The fan was enclosed between two vertical brick walls, and set in position directly over the upcast shaft. The air current ascending from the latter divided into two, and entered the fan through the orifices t, t^1. Motion was imparted to the fan by a pulley actuated by a belt. By reason of its simplicity and regularity in work, this very practical ventilator met with a ready extension. At first the dimensions were modest, owing to the smallness

of the requirements in respect of ventilation then prevailing, the particulars being as follows:—

Diameter of vanes	1·5 metres.
Length of vanes	1·0 metre.
Radius of intake orifice	0·4 to 0·5 metre.
Speed	150 to 200 revolutions per minute.

The depression produced amounted to 18 to 20 millimetres water gauge, and the volume of air delivered to 3 to 5 cubic metres per second. The useful effect was observed to be small, but the power required was also low, being only 3 to 4 horse-power.

COMBES FAN (Figs. 95*a* and 95*b*, Plate XV.).

153. Contemporaneously with the appearance of the Letoret fan, the management of the Grand Cornu mine carried into practical application the idea of Combes with regard to centrifugal fans.

The resulting fan resembled a turbine with curved blades, and was also mounted directly above the upcast shaft. A hole, corresponding to the intake orifice of the fan, was practised in the arched cover, and on this hole was mounted a cast-iron ring *c*, upon which rotated the turbine wheel D. The fan was provided with six curved full blades and an equal number of alternating short blades, attached at the upper side to a disc *d*, and underneath to a flat ring *e*. The disc *c* was fastened to a vertical axis. To make an air-tight joint between the flat ring *e* and the ring *c*, a water seal was formed in the trough *r*, into which dipped an *I*-iron fastened to the under side of the flat ring *e*. The shaft of the fan was prolonged both ways, and mounted on iron girders above and below, motion being imparted by a belt acting on a stepped pulley.

The blades were curved in such a manner that the air entered the fan without any shock, and was intended to be expelled with a very low velocity. This object, however, was not attained in practice.

The dimensions of the fan were as follows:—Diameter of fan to the commencement of the blades, 1·36 metres, to the termination of the latter, 1·7 metres; height of blades, 0·274 metre. The intended speed was 600 to 700 revolutions per minute; depression, 30 to 35 millimetres water gauge; volume of air delivered, 3 to 4 cubic metres per second.

The arrangement of the Combes fan is not simple; the efficiency was low and did not come up to expectation, being only 0·2 to 0·22.

THE CABANY FAN (Fig. 96, Plate XV.).

154. The arms of the Cabany fan were hinged as shown in the drawing, the flat vanes being adjustable. Experiment showed that the most effective angle for the vanes was one of 45 degrees to the plane of prolongation of the arms, the motion of the fan being in the direction indicated by the arrow.

Attention was also bestowed on the centrifugal fan in England, the same theories and experiences being applied there as in Belgium; whereupon the dimensions of the fans were soon increased in conformity with the need for larger volumes of air.

THE BIRAM FAN (Figs. 97*a* and 97*b*, Plate XVI.).

155. The first fan of this class to be used in English mines was that of Biram (Figs. 97*a* and 97*b*). This also was set in position directly over the upcast shaft P, and was provided with eight vanes curved backwards. Communication with the upcast shaft was established by means of apertures on either side of the fan.

Dimensions.

Diameter of fan . . .	6·86	metres	(22½ feet).
Diameter of intake orifice . .	5·5	„	(18 feet).
Width of vanes . . .	1·2 to 1·5	„	(4 to 5 feet).

BRUNTON'S FAN (Figs. 98*a* and 98*b*, Plate XVI.).

156. The arrangement of the Brunton fan recalls that of Combes. It has a vertical axis, and is driven by a horizontal steam engine. The vanes are flat, forty-eight in number, of three different lengths, and arranged vertically. The cover *a* and bottom plate *b* are attached to the vanes, and turn with the latter. The diameter of the fan measures 19½ feet.

THE WADDLE FAN (Figs. 99*a* and 99*b*, Plate XVI.).

157. The Waddle fan was introduced into many English pits. It has a horizontal axis A B, the one bearing being situated in the intake aperture *f*; the other, carrying the driving pulley, on the foundation wall C outside the fan. The vanes are placed between two curved metal casings *p* and p^1, which are attached to a cast-iron piece *m*, mounted on the axis, and connected with the suction neck *f* by means of a stuffing

box. The vanes are alternately long and short, the longer ones beginning at a b, a^1 b^1, and terminating at the periphery a^1 b^1. The discharged air escapes direct into the atmosphere.

One fan of this make measured 39 feet in diameter, and was run at a speed of 60 to 70 revolutions per minute; but others used in English mines measured 40 to 43 feet in diameter. The efficiency (ratio of actual to nominal output) is given as 0·5.

THE RAMMEL FAN (Figs. 100*a* and 100*b*, Plate XVI.).

158. The Rammel fan was first used in connection with the London pneumatic post, to exhaust the air from the conduit pipe (between Battersea and London), and was afterwards employed for purposes of main ventilation in mines. It has thirty-two radial vanes, sixteen of which commence at the periphery of the intake aperture and extend to the outer circumference of the fan, whilst the rest are only half the length of the others, but also reach to the outer surface of the fan. At the central portion the vanes are separated, at right angles to the axis, by a partition which, however, extends only as far as the shorter vanes a^1. The vanes become progressively narrower as the outer extremity is approached, the width at the outer ends being only $\frac{1}{16}$ that at the centre. The shape of the vanes is calculated on such a basis that the passage for the escaping air diminishes in the same proportion as the velocity increases.

Diameter of vanes	27 feet.
Diameter of intake orifice	$4\frac{1}{2}$ „
Breadth of vanes at the intake orifice . .	30 inches.
Breadth of vanes at the periphery . . .	$8\frac{5}{8}$ „
Speed	110 revolutions per minute.

THE RITTINGER FAN (Figs. 101*a* and 101*b*, Plate XVI.).

159. A noteworthy, if not very successful, attempt to improve the capacity and efficiency of ventilating fans is manifested in the one introduced by P. Rittinger.

This fan, which is mounted on a horizontal shaft, is fitted with a cast-iron intake cone a, keyed on to the shaft, and serving to deflect the air entering through the intake orifice s into a vertical direction, parallel to the plane of the fan. The vanes c_1 c are enclosed between two annular sheet-metal plates d and g, one of which, g, is riveted on to the plate of the intake cone a. The vanes are numerous—24 in the specimen illustrated (Fig. 101*a*)—and are curved backwards.

Extending beyond, and in the same plane as the plates *d* and *g*, but separated therefrom by a small intervening space, are mounted board partitions *t* and t_1, to which device the inventor gave the name "diffusor," the idea being that the air expelled by the vanes spreads out in the space between the partitions t_1 *t*, and progressively diminishes in velocity as it approaches the outer edges of same. This device is intended to prevent the unfavourable influence of the higher tension external atmosphere on the low tension air expelled by the fan, and to keep the latter air from flowing back into the fan itself.

The diameter of the intake orifice in Figs. 101*a* and 101*b* is 1 metre (40 inches).

That of the fan, to the commencement of the vanes, is also 1 metre.

That of the whole fan to the ends of the vanes is 1700 millimetres (67 inches).

Axial breadth of fan, 250 millimetres (9⅞ inches).

At the Maehrisch-Ostrau pits Rittinger fans measuring up to 4 metres (13 feet) in diameter were in use, but their capacity was disappointing, being inferior in every respect to the Guibal fan. The mechanical efficiency did not exceed 0·2 to 0·3, and the manometric efficiency was not more than 0·5. Only in a very imperfect manner did the so-called diffusor fulfil its intended purpose of preventing the formation of a vortex between the vanes, preventing a back draught into the fan, and diminishing the effluent velocity of the escaping air; consequently the total effect was far from satisfactory. In fact, these objects were first perfectly attained by enclosing the Guibal fan and widening the effluent shoot of this fan. The efficiency of the Rittinger fan was not appreciably improved, even by the modifications introduced by the inventor during the making of the Mont Cenis Tunnel (see Figs. 102*a* and 102*b*), or by the attachments fitted to this fan by Harzé.

The fan used in ventilating the Mont Cenis Tunnel is horizontal, and mounted on a vertical axis. The diffusor is of annular shape, as shown in the Figure.

160. In the Harzé fan the diffusor was constructed with a number of guide blades, such as are used in the turbine, in which latter apparatus it fulfils its object better, owing to the greater density of water. Subsequently Harzé modified his fan in the direction shown in Fig. 100.

THE KRAFT TURBINE FAN (Figs. 104*a* and 104*b*, Plate XVII.).

161. The fan constructed by Kraft, of the Cockerill Company, for use in the St. Marie shaft at Seraing, corresponds perfectly with the Fourneyron turbine, fitted with internal, fixed guide blades *c* (Figs.

104*a* and 104*b*); except that it was provided with an annular diffusor D, surrounding the fan. The fan itself measures 3 metres in internal diameter, 7·5 metres outside diameter, and 55 centimetres in height. At a speed of 90 revolutions per minute, and a depression of 62 millimetres water gauge, it furnishes 25·83 cubic metres per second.

The manometric efficiency is, however, small, and attains only $62 \div 150 = 0{\cdot}41$.

Only one specimen of the Kraft turbine fan has been constructed and used, being complicated and costly, and inferior in efficiency to the Guibal fan.

Finally, reference may be made to the unsuccessful attempts of Lambert and Aland to improve the centrifugal fan so as to attain the same effects as are furnished by that of Guibal.

162. THE LAMBERT FAN (Fig. 105, Plate XVII.), which measures 13 to 33 feet in diameter, is fitted with eight vanes, and, like other centrifugal fans, a central suction aperture, but is covered by a sheet-metal casing extending over the sides and periphery. Opposite each vane, however, in the peripheral casing, is a slit *a* for the escape of the expelled air. The dimensions of each slit must be in proportion to the volume of air expelled. Though the formation of vortical currents between the vanes, as also the back flow of air into the fan, is prevented, there is an unavoidable loss of energy owing to the high velocity with which the air leaves the fan. The friction is also greater than in other fans; consequently the efficiency is low, and does not exceed 0·36. For this reason, the use of this fan has been discontinued.

THE GUIBAL FAN.

163. The Guibal fan is superior in efficiency to all its predecessors, and to most of them in simplicity of construction and security in working. Since this fan is either coupled direct on to the crank shaft of the driving engine or is driven by belting without any speeding up, it has to be made of large size in order to comply with present-day requirements as regards ventilation. This results in an increased weight, greater difficulty in producing the necessary rigidity of the vanes, and consequently a greater liability of the latter to breakage at high speed. A considerable increase of friction in the bearings is also an accompaniment of augmented dimensions.

It is well known that motors of high power must be made of great size and weight when intended to run at low speed; and this applies equally to fans. On this account many have recently turned attention

to the construction of quick-running fans, with Guibal's improvements, but of smaller diameter. Nevertheless, the Guibal fan represents such an important advance in the construction and efficiency of the centrifugal fan, and is moreover still used in so many large collieries, as to justify an exhaustive theoretical treatment, and complete description of the details. On examining an unenclosed fan, situated between parallel walls, a considerable vortical effect will be observed at the periphery when the fan is running. On standing in front of the fan, and throwing a handful of scraps of paper into the vortex, a portion of these light bodies will be found to be carried out by the air current, whilst another portion will first be drawn in between the vanes and then expelled. This procedure is repeated as often as a fresh lot of paper is thrown in. It is quite evident that the volume of air expelled by the fan is unable to produce a continuous outflow all round. Whilst the vanes produce a compression of the air in front, and drive it outwards, a rarefaction takes place at the rear face of the vanes, thus setting up, simultaneously, a back flow of air as well. This double current explains the low efficiency of the old unenclosed fans. Theoretically it appeared feasible that the back draught could be counteracted by increasing the number of the vanes and curving them towards the rear, as in the Combes fan; but the reverse proved to be the case in practice. The next idea was therefore to enclose the fan in a casing extending nearly all the way round, as in winnowing machines; and this experiment was made in 1855 by Guibal and his pupil Delsaux, at the Escouffiaux pit, Belgium.

Casing the Guibal Fan

164. A fan at the above-mentioned pit, with four flat vanes, was cased as represented in Fig. 106, Plate XVII. On working this fan, however, a strong reflux of air was observed to occur at the point *a*, and therefore the casing was tentatively lengthened by degrees above *a*, until the back flow ceased, the test thus demonstrating the most favourable sectional area for the outlet orifice. It was also recognised that, by suitably regulating the dimensions of the effluent orifice in relation to the pit temperament $\frac{Q^2}{h}$, by means of a sliding damper, the depression could be increased by one-third for any given rate of speed.

Flared Upcast Flue for the Guibal Fan.

165. The air expelled at a given velocity from a ventilating fan still contains a certain kinetic energy, which is usually lost. In order to

reduce this loss to a minimum, Guibal conducted the effluent air into a flue shaped like an inverted pyramid, so that the sectional area, which at the bottom is about the same as that of the air issuing from the fan, is much larger at the mouth. The favourable influence of this flue can be demonstrated arithmetically, and has also been confirmed by numerous experiments.

The flue is most easily constructed of the vertical type; moreover, with this form the air outflow is less liable to be affected by changes of wind, and there is less likelihood of admixed firedamp and coal dust becoming ignited by contact with an adjacent fire than in the horizontal type of flue.

Peclet's experiments have shown that the optimum angle for the discharge of the air into the flue should not exceed 8 or 10 degrees. The lower end of the flared flue should be fitted with a regulating damper.

Details of large (22 feet) Guibal Fan (Figs. 109*a*, *b*, *c*, *d*, *e*, *f*, Plate XVIII.).

166. The movable part of the Guibal fan consists of a wrought-iron or steel shaft, 10 to 12½ inches in diameter, according to the size and weight of the fan. At one end the shaft carries a crank *m* (Fig. 109*b*), for attachment to the connecting rod of the engine, or is fitted with a pulley for belt or rope driving. The other end of the shaft rests in a bearing *p*, reposing on a cast-iron girder, which in turn is supported by a cast-iron chair. The shaft also carries two octagonal rosette plates, O and O′, which are perforated as much as possible in order to prevent the undue reduction of the intake orifice. The prolongations of the rosette arms form eight horns, to which are bolted D-iron rods, which are slightly bent and bolted together at the point of intersection (Fig. 109*g*). For the attachment of the vane boards, angle-irons are fixed on the arms (Fig. 109*d*), to which they are fastened by screws and supporting plates. To prevent warping and distortion, each adjoining pair of the wooden strips are connected at the edges by inset tongues or feathers of cast-iron (Fig. 109*f*). Originally the vanes of the Guibal were made quite flat, thus forming an acute angle with the tangents at the periphery of the fan. The result of this arrangement, however, was to force the air against the casing and the concave side of the flue (nearest the fan), thus robbing the escaping air current of uniformity of movement, and retarding the recovery of energy from the velocity of the escaping air.

For this reason, the iron rods supporting the wooden vanes were

afterwards slightly curved in the direction of rotation, so as to make the outermost portion of the vanes perpendicular to the casing. This enables the air to be gradually diverted into the plane of the flue, and distributed uniformly over the whole area of the latter. Furthermore, in order to ensure the air entering the fan without shock, the inner ends of the vanes are set in a position nearly tangential to the circumference of the intake.

Fans measuring 22 to 30 feet in diameter are fitted with eight vanes, those of larger dimensions being provided with ten, in order to keep the intervening distance and the aperture of the compartments of the fan within bounds. When the breadth of the fan exceeds 8 feet, an extra rosette plate is provided.

The cylindrical brickwork casing is 11 inches thick at the top (one brick thick, plus a facing and lining of cement).

The abutment for the dome of the casing is formed by a cast-iron traverse *g* on the side nearest the flue. The attachment of the flue to the casing usually commences at the point *a*, Fig. 107, on a line O*a* which makes an angle of 45 degrees with the horizontal plane O*e*. The distance O′O varies with the size of the fan, and is also dependent on the distance *dc*, which in turn bears a certain relation to the dimensions of the intake aperture. The height of the flue is from 22 to 30 feet above the axis of the fan, according as the peripheral velocity *u* is greater or less. P (Fig. 109*a*) is a strong door, provided for convenience in inspecting the interior of the fan; *i* is an air chamber, communicating with the intake on the one hand, and with the air conduit on the other. By means of a dam *s*, fitted with several doors, this chamber can be entered without interfering with the working of the fan. The damper *d* is made of oak planking, 4 to 4½ inches wide and about 1 inch thick, fastened by screws on to flexible iron bands 2 inches wide and $\frac{1}{12}$ inch thick. The lower end of the damper is formed of an iron plate bevelled off at the bottom. The whole is held in position by means of two strong eyes at the top, which are connected by chains with a ring attached to a wire rope. This rope passes over two rollers at the mouth of the flue, and thence downwards to a small winch for raising and lowering. The damper edges slide in curved grooves lined with cast-iron (Fig. 109*d*). In order to prevent the shocks otherwise occurring each time one of the vanes passes by the edge of the damper, the lower end of the latter is fitted with an iron plate, of the shape indicated in Fig. 108, so that the vanes do not approach the damper uniformly over the entire breadth.

The foregoing fan is simple, of high efficiency, and very reliable in action, all of which are certainly very valuable properties.

As shown in Fig. 109*b*, the fan intake is on one side only.

167. A Guibal fan, also 22 feet in diameter and 80 inches wide, in use at Fuenfkirchen, in Hungary, is shown in vertical section in Fig. 110*a*, Plate XIX., and in ground plan in Fig. 110*b*, details of the arms being given in Figs. 110*c* and 110*d*. This fan is driven by a steam engine, the cylinder of which is 18 inches in diameter and the stroke 33½ inches, the steam having an admission pressure of 4½ atmospheres, and working with quadruple expansion. At a working speed of 60 revolutions per minute the engine develops a force of 30 horse-power, only 24 of which, however, are transmitted to the fan. Consequently, as the fan delivers 16·66 cubic metres of air per second, at a depression of 40 millimetres water gauge, the actual efficiency is $N_0 = \frac{40 \times 16{\cdot}66}{75} = 8{\cdot}88 \backsim 8{\cdot}9$ horse-power, and the mechanical efficiency E of the whole installation, $\frac{8{\cdot}88}{24} = 0{\cdot}37$.

Determining the useful Dynamic Effect of the Guibal Fan.

168. The coefficient of useful effect expresses the ratio between the useful work done and the motive power consumed. If L_n be taken to indicate the useful work, and L_m the motive power (the indicated energy exerted on the piston by the steam in the cylinder of the motor), then the useful effect will be $E = \frac{L_n}{L_m}$. In the case of ventilating fans the term useful work implies the overcoming of the supplementary hindrances in the production of a ventilating current. As already stated in section 92, this work is expressed by $L_n = \frac{Qh}{24}$ horse-power, wherein Q is the number of cubic metres of air per second, and h the depression in millimetres of the water gauge.

As regards the denominator L_m, or the motive force, opinions frequently differ, so that reports on the efficiency of fans cannot always be employed for comparison without some investigation. Thus some think that the basis of calculation for determining L_m should be the force (L_t) transmitted by the shaft of the motor to that of the driven machine, and measured by the Prony dynamometer, and that consequently $E = \frac{Qh}{L_t}$.

This, however, is inaccurate, inasmuch as, in the expression for L_t, no allowance is made for the supplementary resistances present in the motor.

In order to determine L_m properly, one should rather measure the

force transmitted by the steam to the piston; and this can only be done by means of the indicator. With double-acting steam engines, the taking of indicator diagrams on both sides of the piston is essential. And since, considered from an industrial standpoint, the motor and the driven mechanism form a whole, therefore $E = \frac{L_n}{L_m} = \frac{Qh}{L_m}$, wherein L_m expresses the indicated horse-power of the steam engine.

Guibal's Analytical Theory of Centrifugal Fans.

169. There is no need to discuss the theory laid down by Guibal with regard to ventilators with variable internal capacity, because, as already mentioned, these machines have now gone entirely out of use.

The compartments formed by the vanes of an unenclosed centrifugal fan may be regarded as a succession of tubes *ab*, Fig. 111, rotating about an axial point *x*. The air contained in these channels issues therefrom with two velocities opposed in direction. The one velocity *u*, in the direction of the radius R, is the result of centrifugal force; the other, *v*, is caused by the rotation of the tubes and is tangential to the periphery of the fan. If *w* be taken to express the angular velocity, and *r* and R the inner and outer radii of the vanes, then, in accordance with the laws of mechanics, the velocities *u* and *v* have the following values:—

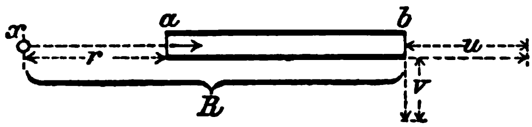

Fig. 111.

$$u = w\sqrt{R^2 - r^2}, \text{ and } v = wR.$$

These velocities correspond to the air pressures—

$$h = \frac{u^2}{2g} = \frac{1}{g^2}w^2(R^2 - r^2) = 0{\cdot}051w^2(R^2 - r^2), \text{ and}$$

$$h' = \frac{v^2}{2g} = \frac{1}{2g}w^2R^2 = 0{\cdot}051w^2R^2.$$

If the weight of air expelled per second is = P, then the power consumed in the operation will be: $L = P \times h = P \times 0{\cdot}051w^2(R^2 - r^2)$ along the radius.

Equally, we have in the tangential direction, $L' = Ph' = P \times 0{\cdot}051w^2R^2$; and the total work: $L + L' = P \times 0{\cdot}051a^2(2R^2 - r^2)$.

The work consumed in the radial direction, however, is all that is exerted usefully, and therefore (frictional resistances apart) the output is—

$$E = \frac{L}{L + L'} = \frac{P\ 0{\cdot}051w^2(R^2 - r^2)}{P\ 0{\cdot}051w^2(2R^2 - r^2)} = \frac{R^2 - r^2}{2R^2 - r^2}.$$

If r is assumed $= o$, then $E = \dfrac{R^2}{2R^2} = 0{\cdot}5.$

Theory therefore shows the impossibility of utilising more than half the power expended in driving an unenclosed fan. In practice it is usual to take $R = 3r$ in the case of Guibal fans, and it therefore follows that—

$$E = \frac{9-1}{18-1} = \frac{8}{17} = 0{\cdot}47.$$

This is consequently the highest theoretical effect of the unenclosed fan. Hitherto we have assumed the tubes to be of equal diameter throughout their entire length: this is, however, not the case with the spaces between the vanes of a centrifugal fan, the sectional area increasing towards the periphery. In the case of straight vaned fans, the air issuing with increasing velocity through the widening channels does not fully occupy same, and therefore we have two zones, as shown in Fig. 112—an outer zone of compressed and effluent air waves s, s, and an adjacent zone Z, with expanding air, in which vortical currents are set up, and where the external air flows back in between the vanes.

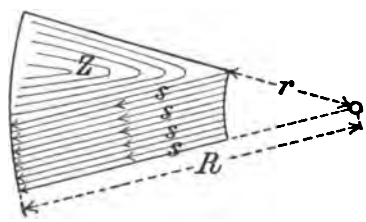

FIG. 112.

This naturally results in a loss of power, since energy is transmitted to the indrawn external air as well; and the following unfavourable consequences ensue.

The useful effect was expressed by $E = \dfrac{R^2 - r^2}{2R^2 - r^2}$, in which it is assumed that only the air drawn through the intake of the fan has to be propelled. If, however, the weight P' of external air drawn into the vortex has to be taken into consideration, the expression will assume the form: $E^1 = \dfrac{2R^2 - r^2}{R^2 - r^2} \times \dfrac{P}{P+P'}$. If now we further assume that—

$P' = \frac{1}{4}P$, then $\dfrac{P}{P+P'} = \dfrac{1}{1+0{\cdot}25} = 0{\cdot}8$, and $E' = 0{\cdot}47 \times 0{\cdot}8 = 0{\cdot}376$.

If $P' = \frac{1}{2}P$ „ „ $= \dfrac{1}{1+0{\cdot}5} = 0{\cdot}66$, „ $E' = 0{\cdot}47 \times 0{\cdot}66 = 0{\cdot}31$.

„ $P' = P$ „ „ $= \frac{1}{2} = 0{\cdot}5$, „ $E' = 0{\cdot}47 \times 0{\cdot}5 = 0{\cdot}235$.

„ $P' = 2P$ „ „ $= \frac{1}{3} = 0{\cdot}33$, „ $E' = 0{\cdot}47 \times 0{\cdot}33 = 0{\cdot}156$.

„ $P' = 3P$ „ „ $= \frac{1}{4} = 0{\cdot}25$, „ $E' = 0{\cdot}47 \times 0{\cdot}25 = 0{\cdot}117$.

„ $P' = 4P$ „ „ $= \frac{1}{5} = 0{\cdot}20$, „ $E' = 0{\cdot}47 \times 0{\cdot}2 = 0{\cdot}094$.

Numerous experiments have proved that the amount $P+P'$ of air discharged by a fan is a constant, that is to say, the smaller the quantity drawn from the external air the more air will be sucked in from the pit.

Hence, if the value of P′ attained 0·5 or 0·75 in the older unenclosed fans, their low capacity is not surprising, the greater part of their activity being consumed in drawing atmospheric air in at the periphery instead of from the pit. The diminution of this back draught, by enclosing the fan and providing a damper for regulating the dimensions of the effluent orifice according to requirements, was therefore a great advance. This modification changed the effect E to E′, namely 0·47, however great the volume of air propelled by the apparatus. It is, however, evident that the loss of energy still remained very high, one source of this loss being the velocity at which the air left the fan and entered the surrounding atmosphere. Combes attempted to counteract this defect by giving the vanes a backward curvature. He imagined the amount of air to be discharged as being under a given pressure, assumed the pit temperature to be $T = \frac{Q^2}{h}$, and determined the effluent area of the fan compartments accordingly.

However, the only occasions on which the desired effect was obtained were those in which the pit temperament was exactly as assumed; not otherwise. Hence any change in the temperament was accompanied by a considerable deterioration in the efficiency of the fan—as was confirmed by Glepin's experiments at the Grand Hornu pit.

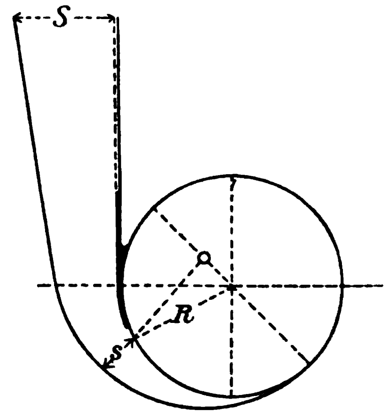

FIG. 113.

Guibal then discovered a better means of utilising the kinetic energy of the air discharged from the fan, with which object he surmounted the enclosed fan with a flared flue. If s be taken to represent the area at the lower end of the flue, by the damper, and S the area at the mouth (Fig. 113), then the energy present in the velocity of the air current will be—

$$L' = P \times 0{\cdot}051(w^2R^2).$$

The velocity will be less at the widened mouth of the flue than lower down, in inverse ratio to the sectional area; *i.e.*, if the air enters the flue through the damper, with a peripheral velocity wR, it will leave the mouth of the flue at a velocity $wR\frac{s}{S}$. This lowered velocity induces an increase in tension, which has a favourable effect on the exhaustion of air from the pit.

The increased pressure is $h'' = 0{\cdot}051\left(w^2E^2 - w^2R^2\frac{s^2}{S^2}\right)$. The useful

tension acting on the suction of air from the pit is compounded of $h'+h'' = H^a$. The utilised proportion of the tangential velocity of the fan (which is equivalent to the velocity of expulsion of air by the fan), recovered by means of the flue, is ascertained by the formula—

$$P \times 0{\cdot}051\left(w^2R^2 - w^2R^2\frac{s^2}{S^2}\right),$$

and the total useful work is expressed by—

$$P0{\cdot}051w^2\left[2R^2 - \left(2R^2 - R^2\frac{s^2}{S^2} + r^2\right)\right],$$

whence the useful effect attains the value—

$$E'' = \frac{2R^2 - R^2\frac{s^2}{S^2} + r^2}{2R^2 - r^2}.$$ If $s = \frac{S}{3}$, $r = \frac{R}{3}$, and $r = 1$, then we have—

$$E'' = \frac{2 \times 9 - 9 \times 0{\cdot}111 + 1}{18 \times 1.} \times \frac{16}{17} = 0{\cdot}94.$$

The final results are therefore—

(1) An unenclosed fan in which the amount of air P, flowing back at the periphery, is equal to the quantity drawn from the pit, exhibits the efficiency $E' = 0{\cdot}47 \times 0{\cdot}5 = 0{\cdot}235$.

(2) An enclosed fan, with damper, has the efficiency $E' = 0{\cdot}47 \times 1 = 0{\cdot}47$.

(3) An enclosed fan, with regulating damper, and flue has—when $s = \frac{S}{3}$—the efficiency $E'' = 0{\cdot}94$.

Hence, theoretically, the provision of a flue doubles the capacity of an enclosed fan.

The Depression produced by the Guibal Fan.

170. We know that the depression produced by centrifugal force $= h$, and that the value of this has been found $= 0{\cdot}051\ (w^2R^2 - w^2r^2)$.

Furthermore, the depression h'' produced by the flue

$$= 0{\cdot}051\left(w^2R^2 - w^2R^2\frac{s^2}{S^2}\right).$$

Hence the total useful tension, or depression, as the effect of centrifugal force and the flue, will be—

$$Ha = h + h'' = 0{\cdot}051w^2\left[2R^2 - \left(R^2\frac{s^2}{S^2} + r^2\right)\right] \quad . \quad . \quad . \quad a.$$

The depression is here expressed by the height of a column of air.

It being inconvenient to employ angular velocities in calculation, the substitution of revolutions per minute (N) is perferable. Then, since $w = \frac{2h'N}{60}$ and $w^2 = \frac{4\pi^2N^2}{60^2}$, we have—

$$H_a = 0{\cdot}051\frac{4\pi^2N^2}{60^2}\left[2R^2 - \left(R^2\frac{s^2}{S^2}+r^2\right)\right].$$

Furthermore, by substituting the diameters D and d for the radii R and r, there ensues—

$$H_a = 0{\cdot}051\frac{\pi^2N}{60^2}\left[2D^2 - \left(D^2\frac{s^2}{S^2}+d^2\right)\right], \text{ or—}$$

$$H_a = 0{\cdot}000139638N^2\left[2D^2 - \left(D^2\frac{s^2}{S^2}+d^2\right)\right].$$

The depression expressed by the height (in metres) of a column of air can be converted into millimetres of water gauge. Taking H_w as the height of the column of water, and 1·133 kilogrammes as the weight of 1 cubic metre of pit air, we then have—

$$H_a : H_w = 1000 : 1{\cdot}133, \text{ and } H_w = \frac{H_a 1{\cdot}133}{1000}, \text{ or in millimetres—}$$

$$H_w = H_a \times 1{\cdot}133 \text{ millimetres. Hence—}$$

$$H_w = 1{\cdot}133 \times 0{\cdot}000139638N^2\left[2D^2 - \left(D^2\frac{s^2}{S^2}+d^2\right)\right] \text{ millimetres, and}$$

$$H_w = 0{\cdot}000158N^2\left[2D^2 - \left(D^2\frac{s^2}{S^2}+d^2\right)\right] \text{ millimetres.}$$

This is the depression theoretically corresponding with the effect of the centrifugal fan.

Now, to ascertain the ratio between the values of the theoretical formula and the practical value of the head of pressure, experiments are necessary.

Numerous trials made with the Guibal fan at different pits have shown that the actual depression attained in practice, $H_e = 0{\cdot}837$ of the theoretical value H_w. By inserting this correction we have—

$$H_e = 0{\cdot}000158N^2\left[2D^2 - \left(D^2\frac{s^2}{S^2}+d^2\right)\right]0{\cdot}837, \text{ or}$$

$$H_e = 0{\cdot}000132N^2\left[2D^2 - \left(D^2\frac{s^2}{S^2}+d^2\right)\right] \quad . \; . \; . \quad A.$$

The formula may be simplified by assuming, as is usual in practice, that $\frac{D}{d} = 3$, and that $\frac{S}{s} = 3$ also. We then obtain—

$$H_e = 0{\cdot}000132N^2 16/9D^2 = 0{\cdot}000132N^2 1{\cdot}777D^2, \text{ or}$$

$$H_e = 0{\cdot}000234N^2D^2 \text{ millimetres} \quad . \; . \; . \quad B.$$

By means of this latter equation it is possible to determine either the diameter D of a fan, or the depression, or the number of revolutions to be made by a fan, provided that in each case the other two factors are of known value.

The value of D being given below, the following values for H_e are deduced for practical use—

When $D = 5$ metres (16·4 feet) $H_e = 0·00585\ N^2$
„ $= 7$ „ (23 „) „ $= 0·011466\ N^2$
„ $= 9$ „ ($29\frac{1}{2}$ „) „ $= 0·018954\ N^2$
„ $= 12$ „ (36 „) „ $= 0·0336696 N^2$
„ $= 14$ „ (46 „) „ $= 0·045864\ N^2$.

Similarly, to attain a depression $H_e = 60$ millimetres water gauge, we have $N = 101$, 72, 56, and 42 respectively, on the basis of the diameters given above. The formulæ A and B give surprisingly accurate results.

171. *Example.*—The Crachet-Picquery Guibal fan measures 7 metres (23 feet) in diameter, D^2 being therefore $= 49$. The diameter of the intake is $d = 3$ metres, hence $d^2 = 9$. The area of the effluent orifice s, under the damper slide, is $= 1$ square metre, and $S = 3·28$ square metres.

Consequently $\frac{s^2}{S^2} = \left(\frac{1}{3·28}\right)^2 = 0·093.$

According to equation A, the depression produced by the fan is—

$$H_e = 0·000132N^2[2 \times 7^2 - (7^2 \times 0·093 + 3^2)], \text{ or}$$

$$H_e = 0·01114N^2 \text{ millimetre water gauge.}$$

When the fan is run at the following speeds the results are—

Revolutions per Minute.	Depression H.	
	Calculated.	Observed.
		Millimetres.
38·5	16·5	17
62	42·82	41
72	57·79	58
89	88·24	85
	205·35	201

The practical output m in depression is therefore $201 \div 205·35 = 0·977$ of that given by the theoretical calculation.

Similar results have been furnished by other Guibal fans.

Setting the Damper Slide of the Guibal Fan.

171. Like any other centrifugal fan, the conditions of working the Guibal ventilator may prove favourable or the reverse, according to the way the damper is set. If the latter be shut too close, a loss of pressure will result from the throttling of the air; if opened too wide, it will admit a back flow of air from the flue and give rise to vortical currents.

To ensure the actual depression values coinciding with those furnished

by the formulæ A and B, it is essential that the aperture of the damper should be increased in proportion to the amount of air drawn from the pit at any given depression. The aperture must also be adjusted in conformity with the temperament or the equivalent orifice of the pit.

The optimum setting of the damper may be experimentally determined by opening it wider, until the maximum of depression per given speed of fan is obtained. This plan, however, is attended with inconveniences: for instance, the maximum depression does not invariably coincide with the maximum intake of air into the fan.

On this account, the damper is often tentatively adjusted in the following manner:—The volume of air traversing the pit is measured, and the result is divided by the speed of the fan in revolutions per second. The maximum amount of air per revolution will then be $g_t = \frac{Q \times 60}{N}$. One can easily understand that it is better to base on the maximum outflow of air than on the maximum depression. In these trials the speed of the motor may be varied in order to determine the most favourable setting of the damper. When once the latter is accurately adjusted, it will be found that the ratio $\frac{Q}{N}$ may be modified within fairly wide limits without disadvantage.

Calculating the Adjustment of the Damper Slide.

172. It is also useful to ascertain the dimensions of the effluent orifice by calculation.

If the area of the damper orifice s be multiplied by a coefficient k (fixed by experiment) and the peripheral velocity μ of the fan, then Q will be the volume of air expelled per second. Hence: $sk \times \mu = Q$ cubic metres, and therefore $\mu = \frac{\pi DN}{60}$.

The value of k is found by observations taken with properly adjusted centrifugal fans. At the Staveley Colliery, k was found $= 0{\cdot}454$; and may usually be taken as $= 0{\cdot}5$.

Hence $s \times 0{\cdot}5 \times \frac{\pi DN}{60} = Q = \frac{s \times \pi DN}{120}$.

Since Q is also $= \sqrt{TH_e}$, then $\frac{s\pi DN}{120} = \sqrt{TH_e}$ . . . (a).

Furthermore, since $H_e = 0{\cdot}000234 N^2 D^2$,

$$N = \frac{1}{D}\sqrt{\frac{H_e}{0{\cdot}000234}}, \text{ or } N = \frac{\sqrt{H_e}}{D \times 0{\cdot}0153} = \frac{65{\cdot}36\sqrt{H_e}}{D}.$$

On substituting this value for N in the above equation (a) we have—

$$\frac{s\pi D}{120} \times \frac{\sqrt{H_e}}{0{\cdot}0153D} = \sqrt{TH_e} = \frac{s\pi}{120 \times 0{\cdot}0153} = \sqrt{T}\text{; whence—}$$

$$s = 0{\cdot}535\sqrt{T}.$$

In this formula the value s of the damper orifice depends solely on the pit temperament T. The breadth of the fan being known, the height to which the damper should be lifted is then easily calculated.

If $L =$ the breadth of the fan, and $l =$ the lift of the damper, then

$$s = l \times L = \frac{0{\cdot}585\sqrt{T}}{L}.$$

For instance, if $L = 2$ metres, and the pit temperament $T = 4$, then

$$l = \frac{0{\cdot}585\sqrt{4}}{2} = 0{\cdot}585 \text{ metre.}$$

Calculating the relative Dimensions of the Guibal Fan, as Function of Pit Temperament.

173. In the expression $H_e = 0{\cdot}000234N^2D^2$, the depression H_e may be maintained constant by modifying the speed N and diameter D; that is to say, the value H_e may be maintained by a certain number of revolutions (or peripheral velocity μ) when the diameter D is modified, or *vice versâ*. The diameter D, however, is also dependent on the temperament T, and must be determined in accordance therewith.

The damper orifice, dependent on the temperament T, is—

$$s = 0{\cdot}585\sqrt{T} = l \times L.$$

Hence there is also a certain relation between the lift of the damper and the diameter D of the fan; and the optimum relation in this connection has been shown by observation to be as follows:—

Let $l = 0{\cdot}08D$, and $L = 0{\cdot}25D$ (which values, though not compulsory, afford a medium basis for calculation), then—

$$l : L = 0{\cdot}08D : 0{\cdot}25D = 0{\cdot}02D^2 = s,$$

and therefore—

$$0{\cdot}02D^2 = 0{\cdot}585\sqrt{T},\ D^2 = \frac{0{\cdot}585}{0{\cdot}02}\sqrt{T} = 29{\cdot}25\sqrt{T}, \text{ and}$$

$$D = \sqrt{29{\cdot}25\sqrt{T}} = 5{\cdot}408\sqrt[4]{T} \quad . \quad . \quad . \quad (1)$$

If the values l and L be replaced by $0{\cdot}1D$ and $0{\cdot}25D$, we have—

$$l \times L = 0{\cdot}1D \times 0{\cdot}25D = 0{\cdot}025D^2 = s.$$

Hence $0{\cdot}025D^2 = 0{\cdot}585\sqrt{T}$, and $D^2 = \frac{0{\cdot}585}{0{\cdot}025}\sqrt{T}$; and hence—

$$D = 4{\cdot}857\sqrt[4]{T}. \quad . \quad . \quad . \quad (2)$$

APPLICATIONS.

174. If T be taken = 4, then $\sqrt[4]{T} = 1{\cdot}414$.

If now $l = 0{\cdot}08D$, and $L = 0{\cdot}25D$, then—

$$D = 5{\cdot}408 \times 1{\cdot}414 = 7{\cdot}65 \text{ metres,}$$
$$l = 0{\cdot}08 \times 7{\cdot}65 = 0{\cdot}612 \text{ metres, and}$$
$$L = 0{\cdot}25 \times 7{\cdot}65 = 1{\cdot}91 \text{ metres.}$$

If $T = 30$, then $\sqrt[4]{30} = 2{\cdot}34$, and therefore $D = 12{\cdot}65$ metres. $l = 0{\cdot}08 \times 12{\cdot}65 = 1{\cdot}01$ metres, and $L = 0{\cdot}25 \times 12{\cdot}65 = 3{\cdot}16$ metres.

A fan of the first-named diameter, if erected at a pit requiring 60 millimetres depression, would discharge—

$$Q = \sqrt{TH_e} = \sqrt{4 \times 60} = 15{\cdot}5 \text{ cubic metres of air per second.}$$

In the second case, with 120 millimetres depression, the current would be $\sqrt{30 \times 120} = 60$ cubic metres per second.

To produce a 60 millimetres depression with a fan 7·65 metres in diameter, the speed required will be $N = \dfrac{65{\cdot}36\sqrt{H_e}}{D}$ revolutions per minute.

This value for N is deduced from the formula $H_e = 0{\cdot}000234N^2D^2$.

$$N^2 = \frac{D^2}{0{\cdot}000234}H_e, \text{ therefore } N = \sqrt{\frac{D}{0{\cdot}000234}} \times \sqrt{H_e} = \frac{65{\cdot}36}{D}\sqrt{H_e}$$

$= \dfrac{65{\cdot}36\sqrt{60}}{7{\cdot}65} = 66{\cdot}18$ revolutions per minute, the volume of air discharged being 15·5 cubic metres per second.

The volume of air discharged in one revolution of the fan will be $q_t = \dfrac{15{\cdot}50 \times 60}{66{\cdot}18} = 14{\cdot}05$ cubic metres.

The cubical capacity of the fan, including the intake, is $\dfrac{\pi}{4} \times D^2 \times 0{\cdot}25D$.

If the breadth of the fan $b = \dfrac{D}{4}$, then the cubical capacity of the fan $= 0{\cdot}785 \times 7{\cdot}65^2 \times 0{\cdot}25 \times 7{\cdot}65 = 86{\cdot}143$ cubic metres.

The ratio between the volume of air expelled per revolution and the cubical capacity of the fan is $\dfrac{14{\cdot}05}{86{\cdot}143} = 0{\cdot}163$.

On applying the same calculation to the second fan, wherein $D = 12{\cdot}65$ metres, it will be found that a speed of 56·65 revolutions per minute is required; 63·548 cubic metres of air will be expelled per revolution; and that, the cubical capacity being $0{\cdot}19625D^3 = 0{\cdot}19625 \times 12{\cdot}65^3 = 397{\cdot}46$ cubic metres, the ratio of air expelled per revolution to this cubical capacity is $\dfrac{63{\cdot}548}{397{\cdot}461} = 0{\cdot}160$.

This ratio is invariable, irrespective of the speed. If, for instance, in the same fan (diameter 12·65 metres), N = 80, then the volume of air expelled per second will be $\frac{Q \times N'}{N}$, since $Q : Q' = \sqrt{H} : \sqrt{H'}$. Again, since $\sqrt{H} : \sqrt{H'} = N : N'$, then $Q : Q' = N : N'$, and therefore—

$$Q' = \frac{60 \times 80}{56 \cdot 65} = 84 \cdot 73 \text{ cubic metres.}$$

The volume of air expelled per second is $q_t = \frac{84 \cdot 73 \times 60}{80} = 63 \cdot 247$ cubic metres, and the ratio $\frac{q_t}{\text{cubic capacity}} = \frac{63 \cdot 547}{397 \cdot 461} = 0 \cdot 160$.

175. *Example* 2.—Calculation of the dimensions of a Guibal fan (for the Gneisenau Colliery, Dortmund) as function of the pit temperament—

$$\frac{Q^2}{H} = \frac{1600}{60} = 26 \cdot 67.$$

If the breadth of the fan be taken as $L\frac{D}{4}$, and the height of the damper orifice $= \frac{D}{10}$, then (according to formula (2), § 173)—

$$D = 4 \cdot 875\sqrt[4]{T}, \text{or } D = 4 \cdot 875\sqrt{26 \cdot 66}$$
$$= 11 \text{ metres.}$$

$$N = \frac{65 \cdot 36}{D}\sqrt{H'} = \frac{65 \cdot 36}{11}\sqrt{60} = 46$$

revolutions per minute.

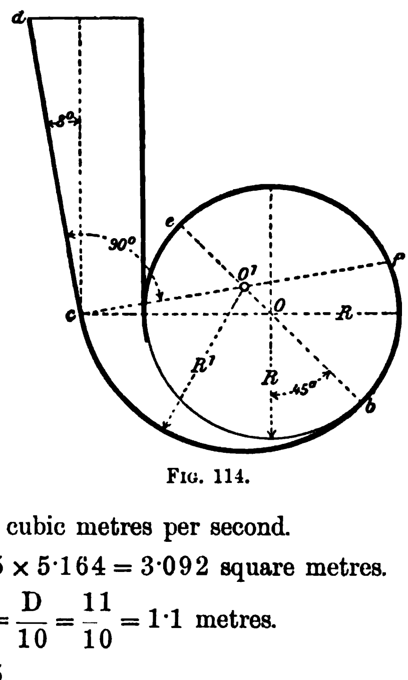

FIG. 114.

$$Q = \sqrt{TH} = \sqrt{1600 \times 60} = 40 \text{ cubic metres per second.}$$
$$s = L \times l = 0 \cdot 585\sqrt{\ominus} = 0 \cdot 585 \times 5 \cdot 164 = 3 \cdot 092 \text{ square metres.}$$
$$L = \frac{D}{4} = \frac{11}{4} = 2 \cdot 75 \text{ metres}; \ l = \frac{D}{10} = \frac{11}{10} = 1 \cdot 1 \text{ metres.}$$
$$s = L \times l = 2 \cdot 75 \times 1 \cdot 1 = 3 \cdot 025.$$
$$R' = R + l = \frac{6}{5}R.$$

The point O′ (Fig. 114) is found by drawing the line *cf* from the point *c*, at right angles to the line *dc* (angle $dcf = 90°$), the point of intersection between *cf* and *eb* then giving O′. The line *eb* makes an angle of 45° with the vertical or horizontal radius R.

USEFUL EFFECT OF THE GUIBAL FAN.

176. The useful effect of the Guibal fan is calculated by the formula—
$E = \frac{L_n}{L_m} = \frac{L_n}{L_n + L_r}$, wherein $L_n = QH$; Q, again, implies the volume of air expelled, and H the actual depression recorded.

L_r comprises both the supplementary resistances in the motor and those of the fan (friction in the motor and fan bearings, vortical currents in the fan, etc.).

These supplementary resistances increase very considerably with the speed. On the basis of experimental results, Guibal assumes that L_r is proportional to the square of the fan speed, and therefore gives $L_r = KN^2$, wherein K implies a coefficient depending on the size and character of the fan.

We thus have for E—

$$E = \frac{QH}{QH + KN^2}.$$

In every fan the value H of the depression varies as the square of the peripheral velocity, or the square of the speed N; so that we may state—

$$H = aN^2, \text{ or } a = \frac{H}{N^2} = \text{constant}.$$

$$\text{Hence } N^2 = \frac{H}{a}, \text{ and}$$

$$E = \frac{QH}{QH + KaH} = \frac{Q}{Q + Ka} \quad . \quad . \quad . \quad (1)$$

Since the volume of air Q expelled by a fan is a function of the pit temperament ($Q = \sqrt{TH}$), we have—

$$E = \frac{\sqrt{TH}}{\sqrt{TH} + Ka} = \frac{\sqrt{T}}{\sqrt{T} + \frac{Ka}{\sqrt{H}}}.$$

From this last formula one can determine the useful effect of E of the fan, provided the values K and a be known.

When a is a known value, K can be determined from formula (1).

$$K = \frac{Q(1 - E)}{aE}. \quad . \quad . \quad . \quad (2)$$

The value of a depends on the mass of the fan.

Since in the Guibal fan the ratio $r : R$ is usually $= 1 : 3$, we then have: $H = 0{\cdot}000234N^2D^2$, whence—

$$N^2 = \frac{H}{0{\cdot}000234D^2} = \frac{1}{0{\cdot}000234D^2}H, \text{ or—}$$

$$\frac{N^2}{H} = \frac{1}{0{\cdot}000234D^2} = a = \text{constant}.$$

For D = 5 metres, the value of $a = \frac{1}{0.000234 \times 25} = 170.94.$

„ D = 7 „ „ „ $a = \frac{1}{0.000234 \times 49} = 87.20.$

„ D = 9 „ „ „ $a = \frac{1}{0.000234 \times 81} = 52.72.$

„ D = 11 „ „ „ $a = \frac{1}{0.000234 \times 121} = 35.30.$

„ D = 12 „ „ „ $a = \frac{1}{0.000234 \times 144} = 30.00.$

For the purposes of determining the value of K (formula 2) numerous experiments have been carried out.

At the Crachet-Picquery Colliery the value E was found = 0·611 for a fan 7 metres in diameter, the value of Q being = 23·74 cubic metres. Since, for a fan of these dimensions, the value $a = 87.20$, it follows that—

$$K = \frac{23.74(1-0.61)}{0.61 \times 87.20} = 0.175, \text{ and}$$

$$Ka = 0.175 \times 87.2 = 15.42.$$

The pit temperament at Crachet-Picquery was 6·43, and the depression = 85 millimetres water gauge; so that—

$$E = \frac{\sqrt{T}}{\sqrt{T} + \frac{Ka}{\sqrt{H}}} = \frac{\sqrt{6.43}}{\sqrt{6.43} + \frac{15.42}{\sqrt{85}}} = 0.602.$$

Accordingly the useful effect of a fan depends on the pit temperament, the depression H, and the coefficient K. When the value of H rises, the denominator in the fraction for E is reduced, and the useful effect consequently greater. The same thing happens when the temperament rises, *i.e.* the resistance of the pit is diminished.

Example 2.—The Guibal fan at the Staveley Colliery measures 9 metres (29½ feet) in diameter. For a depression H = 54·61 millimetres water gauge, Q = 40 cubic metres per second (1412·66 cubic feet), the value of E being found = 0·61. Hence—

$$T = \frac{Q^2}{H} = \frac{1600}{54.61} = 29.29.$$

$$\sqrt{T} = \sqrt{29.29} = 5.415.$$

$$Ka = \frac{Q(1-E)}{E} = \frac{40(1-0.61)}{0.61} = 25.56.$$

According to the formula, therefore—

$$E = \frac{\sqrt{T}}{\sqrt{T} + \frac{Ka}{\sqrt{H}}} = \frac{5.415}{5.415 + \frac{25.56}{\sqrt{54.61}}} = 0.61.$$

In the case of a Guibal fan 9 metres in diameter, at the Sacré-Madame pit, the value of Ka was found = 28·45.

DEDUCTIONS.

177. From the foregoing it may be concluded that enclosed Guibal fans, fitted with widened flues, furnish degrees of useful effect far surpassing those of older centrifugal fans.

Numerous experiments have also been carried out by Gille and Franeau with the fan at Crachet-Picquery. At first, in order to determine the supplementary resistances in the steam engine and fan, the latter was run without vanes; and in this manner it was found that, at a speed of 18·75 revolutions the supplementary resistances consumed a force of 1·4 horse-power, which increased to 24·8 horse-power on the speed being raised to 75 revolutions. That is to say, these resistances increased almost precisely as the square of the speed, since $\frac{18{\cdot}75^2}{75^2} = \frac{1{\cdot}40}{x} = 22{\cdot}40$ horse-power, instead of the 24·80 horse-power found.

On attaching the vanes, and gradually adding the casing, damper, and flue, the following values were obtained for the useful effect:—

	Minimum Useful Effect.	Maximum Useful Effect.	Mean Useful Effect.
1 Without casing	0·16	0·22	0·19
2. With casing	0·09	0·31	0·20
3. ,, and flue	0·26	0·57	0·415
4. ,, flue, and damper	0·38	0·61	0·495

The favourable influence of the damper would have been still more apparent if the pit temperament during the experiment had been less in accordance with the condition for which the fan was specially designed (Q = 30 cubic metres per second, H = 80 millimetres, and T = 11·25, instead of 6·63 in the experiments).

The following conclusions were drawn from these experiments by Gille and Franeau:—

(1) Below a certain speed (25 revolutions per minute) the casing has an unfavourable influence, but at higher speeds its action is progressively more advantageous up to about 75 revolutions. Above this limit the good effect of the damper remains constant.

(2) The beneficial effect of the flared flue is shown at all speeds, and is greater in proportion as the speed of the fan increases.

(3) A properly adjusted damper increases the useful effect of the fan in all cases.

According to the experiments of Gille and Franeau, the average useful effect of the Guibal fan may be set down as 0·50.

Apparent and Real Depression.

178. The engine room of every power fan installation must be fitted with a pressure gauge to record the depression produced in the air conduit in front of the fan. In the Breslau mining district the provision of an automatic pressure recorder—*e.g.* the Ochwadt pressure gauge—is compulsory in all fiery pits, and the diagrams drawn by the instrument must be retained for at least two months.

It should here be remarked that the depression H_1, produced by the fan, does not comprise or indicate the rarefaction H'', arising from natural causes in the pit. Various causes unite to produce a natural ventilating current in most pits, as may be easily noticed from the fact that, on stopping the ventilating fan, a current, of diminished intensity it is true, still continues to escape from the flue of the fan. This current is due to the effect of differences in temperature in the intake and upcast shafts. It is, however, impossible to measure the tension of this natural current by means of the gauge at the mouth of the upcast shaft, since this gauge immediately sinks to the zero point when the fan is stopped. This is explained by the fact that the pressure necessary to the inception of a natural ventilating current is consumed in overcoming the resistances encountered in the pit, and therefore cannot be measured by the gauge in the upcast. Hence it is necessary to perform the measurement in another way.

The actual and true air tension H to be determined in working a fan is $H = H' \pm H''$. In this equation it is necessary to write $\pm H''$, since it may happen that the natural air current acts in opposition to the artificial one, and therefore hinders instead of facilitating it. True, this is a rare eventuality, being usually due to an unskilful selection of the upcast shaft; nevertheless, it is always possible, and in some cases even inevitable. The plus sign applies to cases where the natural current assists the artificial one, the minus sign to the converse eventuality. Hence, in the foregoing equation the value H, the real tension in the mouth of the upcast, must remain an unknown quantity until the value H'' of the natural current has been determined; whereas H' can be read off on the pressure gauge of the fan. The value of H'', however, may be simply ascertained by making two observations with the fan running at

different speeds, and reading off the corresponding volumes of air Q_1 and Q_2, together with the pressures H_1 and H_2. Then, since the actual tensions vary as the squares of the corresponding volumes of air, we have—

$$H_1+x : H_2+x = Q_1^2 : Q_2^2.$$

Here x indicates the tension of the natural air current, H_1 and H_2 the apparent depressions read off on the gauge.

This equation gives us $x = \frac{Q_1^2 H_2 - Q_2^2 H_1}{Q_2^2 - Q_1^2}$ millimetres water gauge. A

Example—

179. Suppose the value Q_1 to be $= 18\cdot33$ cubic metres in the first test, and $Q_2 = 24$ in the second; $H_1 = 30$ millimetres gauge, and $H_2 = 60$ millimetres, the natural current in this instance assisting the artificial current, then the natural air pressure will be: $x = \frac{18\cdot33^2 \times 60 - 24^2 + 30}{24^2 - 18\cdot33^2}$ $= 12$ millimetres.

Hence the actual depression in the first instance is $H = 30 + 12 = 42$ millimetres; in the second, $60 + 12 = 72$ millimetres. The amount of air drawn through the pit in the first case is $Q_1 = 18\cdot33$ cubic metres; and, in the second case, $Q_2 = 24$ cubic metres.

According to the first experiment, the real temperament is $Tr = \frac{Q^2}{H} = \frac{18\cdot33^2}{42} = 8$; and, according to the second, also $Tr = \frac{24^2}{72} = 8$.

The true specific resistance and the true equivalent orifice can be determined in the same way, the apparent depression being replaced by the true depression as a basis for the calculations.

Defects and Imperfections of the Improved Guibal Fan.

180. Although the improved Guibal fan is far superior in efficiency to the older types, and is scarcely inferior to the newer small quick-running fans, besides being quite as reliable in working as fans of any other type whatsoever, it is nevertheless still attended with certain features to which objections can be urged.

The Guibal fan is primarily intended to be coupled direct with the driving motor, without the interposition of any speeding gear, so that the speed of the fan is the same as that of the motor. Consequently, when a higher depression is to be produced, and a greater volume of air propelled, the diameter of the fan must be increased, in order to furnish the necessary peripheral velocity—a product of the radius and the angular velocity.

Guibal avoided high speeds, for the reason that the supplementary resistances increase as the square of the speed. On the other hand, very large fans are of great weight, and consequently involve a deal of loss by friction, besides taking up a deal of room—a particularly inconvenient quality in underground chambers; moreover, the prime cost is high, the expense of foundations and mounting is considerable, and, finally, they are less suitable than smaller fans for use in pits with small equivalent orifice, low temperament, or high specific resistance. Again, since the fan is enclosed about three-quarters of the way round, the air can only escape from about one-fourth of the periphery, the result being compression in the remitting portions, and shocks which, in the case of very large fans especially, may set up vibration in the arms and vanes.

Now, vibration is not very far removed from breakage. To prevent this, and its characteristic humming noise, Guibal, as already mentioned, shaped the lower edge of the damper slide like a swallow's tail; nevertheless, it is still indispensable to make the arms of large fans very strong, and to stay the vanes effectually—which, however, is frequently omitted in practice.

If these hints be adopted, the Guibal fan will be found to fulfil its purpose very well, and capable of running at a somewhat higher speed than usual when occasion arises.

CHAPTER VIII.

DETERMINING THE THEORETICAL, INITIAL, AND TRUE (EFFECTIVE) DEPRESSION OF THE CENTRIFUGAL FAN—NEW TYPES OF CENTRIFUGAL FAN.

Theoretical Depression.

181. As already mentioned, the rarefaction or depression produced by the centrifugal force of a fan is $h = \frac{1}{2g}(w^2R^2 - w^2r^2)$, wherein R and r denote the internal and outer radii of the fan.

The rarefactive action of the flared flue attached to the fan has also been determined as : $h'' = \frac{1}{2g}\left(w^2R^2 - w^2R^2\frac{s^2}{S^2}\right)$, wherein s and S denote the sectional area of the lower orifices of the flue. Hence the total rarefactive action Ha is—

$$Ha = h + h'' = \frac{1}{2g}(w^2R^2 - w^2r^2) + \frac{1}{2g}\left(w^2R^2 = w^2R^2\frac{s^2}{S^2}\right).$$

If now, in the equation for h, the internal radius be regarded as zero, or of so small a value as to be practically negligible, then we have $h = \frac{1}{2g}w^2R^2$, or if w^2R^2 be taken as equal to the square of the peripheral velocity, *i.e.* μ^2, $h = \frac{\mu^2}{2g}$.

In the second equation : $h'' = \frac{1}{2g}\left(w^2R^2 - w^2R^2\frac{s^2}{S^2}\right)$, the value $w^2R^2\frac{s^2}{S^2}$ is also equal to zero if it be assumed that the upper sectional area of the flue is infinitely great, so that the effluent velocity of the escaping air = 0. We then have $h'' = \frac{\mu^2}{2g}$. Hence $h + h'' = Ha = \frac{\mu^2}{2g} + \frac{\mu^2}{2g} = \frac{\mu^2}{2g}$.

Expressed in millimetres of water gauge, when 1 cubic metre of pit air weighs 1·133 kilogrammes, we have $Ha = \frac{\mu^2 \times 1 \cdot 133 \times 1000}{g \quad 1000} = \frac{1 \cdot 133\,\mu^2}{g}$ millimetres. . . . (A)

This result is the theoretical depression of a fan, in the absence of any supplementary resistance (friction, vortices, etc.) to the passage of air therethrough, and with an effluent velocity $= 0$ on the part of the air issuing from the flue. In reality, these values are of course unobtainable from any fan, however well designed; nevertheless, it is evident that the effect of the fan must be the greater the closer the resulting depression approaches the theoretical value Ha. By this means we have a method for comparing fans of different construction, and of determining which produces the best manometric effect, *i.e.* which gives the greatest depression for any given peripheral velocity. Furthermore, since the temperament $T = \frac{Q^2}{h}$, and therefore Q, the output of air from the fan, is a function of the air tension h, a higher tension will generally correspond with the passage of a larger volume of air through the fan.

Initial Depression.

182. From the foregoing it will be evident that the theoretical depression can only be determined by calculation, and not by observation.

On the other hand, the initial depression can be ascertained when the fan is running, by entirely closing the intake orifice, whereupon, of course, no air can flow through the fan, and therefore the depression in front of the fan must be at a maximum.

The initial depression can be rendered visible to the eye by closing the intake. We have here a new means of comparing the initial depression produced by different fans at an equal peripheral velocity μ.

Effective Depression.

183. If any fan be allowed to run at any given peripheral velocity, then, for any given temperament, there will result a certain depression, which is termed the effective or actual depression. Generally speaking, fans of different construction will give different results (other conditions being equal), since divergent supplementary resistances within the fans themselves will have to be overcome, and consequently they are not all able to utilise the same peripheral velocity to an equal extent.

The higher the depression produced in any fan at a given peripheral velocity, the better will the fan fulfil its purpose; consequently the smaller will be the inherent supplementary resistances, and the greater the output of air.

On dividing the effective depression by the theoretical one,

$Ha\frac{\mu^2\delta}{g}(\delta = 1{\cdot}133)$, the manometric efficiency is obtained; and this enables one to ascertain which type of a fan under comparison offers the smallest amount of supplementary resistance to the passage of a given volume of air.

In the case of Guibal fans, the mean manometric efficiency is 0·53.

Prime Cost of Installing a Guibal Fan.

184. (1) The cost of a Guibal fan, measuring 7 metres (23 feet) in diameter, 2·1 metres (83 inches) broad, and weighing 310 cwt.,

plus cost of setting, is . .	8,400	shillings	
The casing, flue, and air conduit cost .	3,000	,,	
The 30 to 35 horse-power engine, for driving same, with boiler and engine house, etc., costs . . .	15,000	,,	
Total . . .	26,400	,,	(£1320)
(2) A Guibal fan, 9 metres ($29\frac{1}{2}$ feet) in diameter, 3 metres wide (10 feet), erected at the Von der Heydt pit, Saarbruecken, cost . . .	13,500	,,	
Buildings, conduits, foundations, etc. .	18,600	,,	
Total . . .	32,100	,,	(£1605)
(3) A Guibal fan, 9 metres in diameter, and $2\frac{1}{2}$ metres ($29\frac{1}{2}$ feet) wide, at the Julie pit, Westphalia, cost, with engine	12,300	,,	
Condenser, feed-pump . . .	3,150	,,	
Two boilers, pipes, etc. . . .	6,000	,,	
Total . . .	22,500	,,	(£1102)

An average estimate for a 9-metre ($29\frac{1}{2}$ feet) Guibal fan, installed with engine, boilers, and buildings, amounts to £1750 to £2000.

According to the report of the Prussian Firedamp Commission, the average cost of the seventy-eight Guibal fans in use in Prussian pits amounts to 30,407 marks (£1520), without reckoning the air shaft and boilers. The most expensive fan of this type mentioned in the above report is the one (9 metres in diameter) at the Wilhelm shaft of the Koenigin Elisabeth pit, in the Ruhr district, the cost of which was 72,810 marks (£3640), the next dearest being a 10-metre fan at the Friedrichsthal pit, which cost 50,500 marks (£2525). The cheapest

Guibal fan cited was one of 9 metres diameter, at the Schlaegal und Eisen pit, costing 8880 marks (£444). The engine for this fan cost £339.

A Guibal fan, 7 metres in diameter, installed underground, cost 34,672 marks (£1733), including 7721 marks (£376) for constructing the underground chamber. (The fan, engine, and pipes alone cost 20,526 marks (£1026)).

The working expenses and depreciation of a Guibal fan are set down at 9046 marks (£452).

MODIFICATIONS OF THE GUIBAL FAN.

THE DINNENDAHL FAN (Figs. 115*a* and 115*b*, Plate XX.).

185. The Dinnendahl fan belongs to the class of large-diameter fans similar to that of Guibal, and, like the latter, is coupled direct on to the shaft of the motor. The Guibal improvements are adopted, and the vanes are of the same shape and number; but, instead of the casing fitting close to the rim of the fan, it gradually recedes from the latter spirally, commencing from the abutment on the flue wall, and gradually merges into the opposite sloping wall of the flue. In consequence of this arrangement the damper is dispensed with, there is no compression of the air within the vane compartments as in the Guibal fan, the air issues continuously and without shock over the entire periphery of the fan, and there is no longer any tendency to vibration in the vanes. Nevertheless, the air in the spiral chamber tends to flow back between the vanes and thus set up vortical currents. True, the inventor endeavoured to obviate this defect by making the fan narrower than the corresponding Guibal fans, the vanes of an 8-metre fan measuring only 2 metres (80 inches) across : it would, however, have been better to taper the vanes towards the outer end, as was done in the Rammel fan (Figs. 100*a* and *b*), the Waddle fan (99*a* and *b*), and that of Brunton (Figs. 98*a* and *b*). Furthermore, Dinnendahl provides an intake orifice of correspondingly smaller diameter at each side of the fan, fits intake cones on the fan shaft, and divides the fan space into two compartments by means of a partition extending half-way up the vanes. The arms and vanes are entirely constructed of wrought-iron, and are stiffened by wrought-iron bars, angle irons and plates. The domed cover of the casing is also of iron, only the under portion and the flue being of brickwork.

THE KLEY FAN.

186. Kley, of Bonn, attempted to further improve the construction and efficiency of the Guibal fan. At first his fans were also coupled

direct to the shaft of the motor, and had a diameter of 8 to 9 metres (26 to 29 feet). Afterwards he built smaller fans, 4 to 5 metres (13 to 16 feet) in diameter, driven by ropes, the speed being geared up as 1 : 3, so as to work at about 150 revolutions per minute. Finally, however, he reverted to large direct-coupled fans. The vanes are up to 16 in number. A peculiar feature of the Kley fan is the spiral intake, which was first applied to a fan constructed for the Schmidtmann shaft, Aschersleben (Figs. 116*a*, *b*, and *c*). This spiral chamber, which was afterwards provided on each side of the fan (Fig. 116*d*), causes the air to enter the fan with a movement corresponding in direction with that of the fan itself, the idea being to economise motive power. However, the entire fan space is wide, complicated, and difficult to arch over. It is probable that the favourable effect of the spiral intake is nullified by the consequent double bend at right angles necessarily made by the incoming air.

The arch of the fan casing is given a spiral shape, commencing from the inner wall of the flue, and, in the later models, a diffusion chamber is also provided; and on this account the vanes are tapered towards the outer extremity, to prevent an increase in the velocity of the air traversing the cells of the fan, and also to avoid back draught and vortical currents. The last-named tendency is furthermore counteracted by the increased number of vanes and the resulting reduction in the size of the individual cells.

In the newer patterns of the Kley fan the fan chamber is surrounded by an annular diffusion chamber, which is widened towards the outer side, and is in turn surrounded by the spiral effluent chamber. This reduces the effluent velocity even before the air enters the flue. The shape of the vanes also differs from the theoretical form, inasmuch as the outer ends are curved forwards, so as to form an angle of 20 degrees with the tangents, whilst the inner ends enclose a forward acute angle, so that the air may enter the fan without shock.

The vanes are made of sheet-iron, and are curved in a circular form (see Figs. 117*a* and *b*, representing the Kley fan at the Osterfeld pit, and Figs. 118*a* and *b*, showing the one at the Bismarck pit).

The working effect of the Kley fans, especially the newer patterns (see Figs. 118*a*, *b*, and *c*, Plate XXIV.), where excessively constricted intakes have been avoided, is said to be as much as 0·71, and therefore higher than that of the Guibal fan; but, on the other hand, their arrangement is less simple, and the cost of installation is consequently greater. The manometric effect is also said to be higher than that of the Guibal fans.

NEW TYPES OF CENTRIFUGAL FAN OF SMALL DIAMETER AND HIGH WORKING SPEED.

187. Owing to the high friction, heavy prime cost, and large space occupied by direct-coupled fans, like those of Guibal and others, attempts have been made to construct fans to be driven by ropes or belting, smaller in size, lighter and cheaper, but capable of approaching, and even surpassing, the larger fans in volume of air propelled, as well as in point of mechanical and manometric efficiency. Of course, in small fans there is the difficulty that, where a large volume of air has to traverse a comparatively narrow fan space, it must do so at an increased velocity, and that the resistance increases as the square of the velocity.

Consequently, in constructing such small fans, care has to be taken to reduce the absolute dimensions of the resistance to a minimum, by making the conduits as smooth internally as possible, avoiding dead angles, sudden changes of sectional area, and sudden and acute curves. It will be readily apparent that the reduction in diameter of these fans has often been carried to extremes, just as the proper dimensions have occasionally been exceeded in the construction of large fans.

These small quick-running fans usually have twice or three times as many vanes as the large fans.

THE PELZER FAN (Figs. 119*a*, *b*, *c*, *d*, *e*, *f*).

188. The Pelzer fan is made in a variety of sizes, ranging from small hand fans, for separate ventilation, to those of 4 metres (13 feet) diameter for the ventilation of an entire pit. A special feature is the lateral air intake, parallel to the axis of the fan (see Fig. 119*a*), wherein the air encounters the straight conical surface *k* of the fan. The vanes *zz*—8 to 16 in number, according to the size of the fan—are attached in a normal manner to the conical bottom *k* of the fan, and radiate from the shaft, forming plane surfaces, between which the air enters in a straight line, and is diverted towards, and is expelled from, the periphery of the fan by the deflecting effect produced by the conical bottom. In the newer and larger patterns of this fan the outer edges of the straight vanes are fitted with exhaust paddles *ss* (Figs. 119*a*, *b*, *c*), which are curved forwards and serve to draw the air into the fan without shock.

The newer Pelzer fans, for main ventilation, are surrounded by a spiral casing, which discharges into a flared flue (see Fig. 119*e*).

The fan illustrated in Fig. 119 measures 4 metres (13 feet) in diameter, 800 millimetres (31 inches) in width, and was constructed for

the Friedrichsthal pit, Saarbruecken. The mechanical efficiency of these fans is stated to be 0·54 to 0·62; the speed, 90 to 150 revolutions per minute. Smaller patterns are run at speeds of 200 to 300, and even more, revolutions per minute.

Cost of Pelzer Fans.

The cost of installing a small Pelzer fan, 1·6 metres ($5\frac{1}{4}$ feet) in diameter, set up underground at the Heilbrun salt mine, was as follows:—

Fan, including freight . .	1500·00	shillings	
Excavating and masonry . .	572·36	„	
Guide pulleys, girders, bolts, driving rope, etc. . . .	327·64	„	
Total . . .	2400·00	„	(£120).

The working expenses, with a consumption of 18 horse-power and a delivery of 1200 cubic metres of air per minute, amounted to 2·8 shillings per diem.

According to the report of the Prussian Firedamp Commission, the average cost of the 22 Pelzer fans at work in Prussian mines amounted to 9939 marks (£497), of which sum 7128 marks (£356, 9s.) falls to the account of the motor engines. The most expensive of these fans—that at the Maybach shaft, Saarbruecken (a 4-metre fan)—was 30,630 marks (£1531, 10s.), including 2560 marks (£125) for the engine.

The Geisler Fan (Figs. 120*a*, *b*, *c*, *d*).

The Geisler fan is probably one of the best and most skilfully designed of the quick-running fans, comprising both the improvements introduced into the Guibal fan, with low intake and internal resistances. Excessive velocity is obviated by a correspondingly large diameter (up to $4\frac{1}{2}$ metres); and there is nothing in the way of constructing these fans of still larger diameter when required by the volume of air to be propelled.

As a rule this fan is fitted with a single intake and an intake cone. To prevent vortical currents, the fan is provided with a large number of vanes (48 in a fan of $3\frac{1}{2}$ metres—$10\frac{3}{4}$ feet—diameter), tapering towards the outer end. As in the Guibal fan, the vanes are arranged radially at the periphery, but are curved forwards at the intake, in order to avoid concussion. Furthermore, they are fastened on one side to the flat bottom plate of the fan, and are covered on the other by a ring of sheet-metal so as to form cells enclosed on four sides.

The end of the intake conduit nearest the fan is widened, in conoidal form, to do away with sharp corners at this part.

The casing fits close against the fan in one place only,—on the side of the flue, from which point onwards it tapers spirally to the outer wall of the flue. It also widens gradually in a transverse direction from the ends of the vanes (see Fig. 120*c*), the side walls becoming parallel only after a certain interval therefrom. The necessary diminution in the velocity of the effluent air is completed in the tapered flue.

Motion is generally transmitted from the engine by hempen ropes. The fan projects free on the end of the driving shaft, and can be removed, on the side opposite the intake, when the bearing frame is dismounted. In order to set the fan exactly in the proper position in the casing, and fix it there, an adjusting device is attached to the outer extremity of the shaft, which is capable of a slight lateral movement in the bearings. The shaft itself is mounted in Sellers' ball bearings.

A Geisler fan, 4½ metres (14½ feet) in diameter, has been installed at the fiery Hibernia Colliery, Gelsenkirchen, for ventilating the entire workings. Particulars of the results obtained with this fan have been published by Bergrath Behrens in his monograph *Beiträge zur Schlagwetterfrage* ("The Firedamp Problem"). The fan was designed by its inventor and constructor to furnish 5000 cubic metres of air per minute (83·33 per second), at a working speed of 160 revolutions, with a depression of 100 millimetres water gauge, and an equivalent pit orifice *a*, 3·2 square metres. In practice, however, this output has been exceeded.

The following tabular results with the above fan are taken from Behrens' work already referred to:—

No. of Experiment.	Date. Month.	Day.	Year.	Speed of Fan, Revolutions per Minute.	Indicated Horse-power.	Actual Depression, Millimetre Water-gauge.	Theoretical Depression, $\frac{\mu^2\delta}{g}$, wherein $\delta = 1{\cdot}2$ Kilos.	Manometric Efficiency.	Peripheral Velocity, μ, Metres per Second.	Volume of Air, o, Discharged Cubic Metres per Second.	Equivalent Orifice, $a = \frac{0{\cdot}38Q}{\sqrt{h}}$	Temperament, $\frac{Q^2}{h}$	Mechanical Efficiency of Fan and Motor.	Velocity of Air Current through the Fan Metres per Second.	Remarks
						mm.	mm.		m.	cub. m.	sq. m.			m.	
7	11	5	1894	152	203	80	162	0·51	35·8	98·85	4·29	109·6	0·51	19·77	
13	2	3	1896	138	...	48	129·6	0·371	32·51	100·6	5·64	210·8	...	20·1	
14	2	17	1896	140	181·1	45	133·2	0·34	32·97	104·1	6·02	240·0	0·34	20·8	
15	2	17	1896	150	213·7	56	152·4	0·37	35·42	110·3	5·72	217·2	0·39	22·06	
16	3	7	1896	160	209·4	125	173·8	0·72	33·69	203·1	3·61	86·5	0·82	20·06	Sectional area of pit artificially reduced.

As will be seen from the table, the manometric efficiency differed only slightly from the mechanical efficiency. Only in experiment No. 16, with artificially diminished equivalent orifice, did the mechanical efficiency come out higher, whilst both were very large. Experiments Nos. 13, 14, and 15, which were performed with the large equivalent orifice 5·64 to 6·02, show that with the reduction of the pit resistance and the increased sectional area of the galleries the efficiency of the Geisler fan is reduced in no inconsiderable degree. Behrens rightly concludes that the selected fan diameter, 4½ metres, is still too low for such conditions. Probably the width of the fan is also insufficient. The dimensions are given in Fig. 121, Plate XXVI.

The superficial area of the narrowest part of the intake conduit $f_1 = 5{\cdot}72$ square metres; at the commencement of the inner ends of the vanes F_2 it is 5·0, and the same at F_3, so that this figure must be taken as the average for the interior of the fan. This was the basis employed in the calculations detailed in the foregoing table.

From the experiments in question, it must be concluded that the height of the actual depression produced by the fan at the intake conduit —and which at the same time also expresses the dimensions of the pit resistance (or, really, the ratio of the equivalent orifice to the transverse sectional area of the fan)—determines the manometric and mechanical efficiency of the fan, since both the volume of air delivered and the velocity of transit through the fan varied but slightly in all five tests, and therefore could not so differently affect the efficiency. According to the experiments, the optimum ratio between the equivalent orifice of the pit and the width of the fan would be 3·61 : 5, or 1 : 1·4.

An underground Geisler fan (diameter, 3½ metres—10¾ feet), at the Shamrock pit, Westphalia, was designed to furnish 50 cubic metres per second. It cost 68,000 marks (£3400), of which sum, however, 30,000 marks (£1500) represented the outlay in making the underground chamber and connections.

Although of medium or small diameter, Geisler fans are scarcely less expensive than large Guibal fans, especially when the flared upcast flue is made, as is customary, of sheet-iron.

The annual working expenses of the Geisler fan at the Shamrock pit are stated to amount to 15,600 marks (£780).

In exceptional cases Geisler fans are provided with a double intake, and are therefore double fans, as shown in Figs. 122*a* and *b*.

The following table, giving the cost, weight, and output of Geisler fans of different sizes, is taken from Hoefer's *Pocket-Book*:—

WEIGHT, DIAMETER, SPEED, AND PRICE OF GEISLER FANS (AFTER HOEFER).

Diameter of fan, metres .	1·8	2·0	2·5	3·0	3·5	4·0	4·5
Maximum number of revolutions per minute .	920	830	660	550	475	415	370
Maximum volume of air discharged, cubic metres per second . . .	18·33	26·67	35·83	50·0	68·17	90·0	115·0
Equivalent orifice of pit a in square metres .	0·833	1·21	1·63	2·27	3·14	4·10	5·25
Total weight of iron parts in tons (1000 kilogrammes) . . .	5·000	5·500	6·500	9·000	12·500	17·000	22·500
Price	£262, 10s.	£278, 5s.	£320, 15s.	£383, 5s.	£477, 15s.	£588	£708, 15s.

THE CAPELL CENTRIFUGAL FAN (Figs. 123*a* and *b*).

The Capell fan, the size of which ranges from 2 to 6 metres (6½ to 20 feet) in diameter, is really a small inner fan placed within a larger one. The outer fan is surrounded by a spirally widened casing, which opens into a short hopper-shaped flue, only about 80 inches high. The intake is on both sides, and on this account the fan is divided into two equal parts by means of a circular partition, so that we have here really to do with a double fan. The inner and outer vanes in each division are curved outwards in a direction opposite to that of their movement, and are displaced to form a certain mutual angle (see Fig. 123*a*).

According to the inventor, the inner vanes perform the actual useful work, whilst the outer ones merely serve the purpose of a diffusion chamber, and convey the air outwards. It is, however, difficult to find any theoretical grounds for this peculiar arrangement of the vanes. All that can be said is that it results in the production of a number of corners and angles which cannot possibly facilitate the passage of the air through the fan, though no unfavourable consequences have come to light in the trials made with the Capell fan. Nevertheless, these published results justify some mistrust. Thus von Hauer, in his work on mine ventilation, quotes an English source for the statement that an unenclosed Capell fan, without flue, has been found to give a working efficiency of 68 per cent. Such a high figure, however, has been demonstrated impossible by Guibal. Hence one is also justified in casting a little doubt on the favourable results reported as having been obtained by the enclosed Capell fan; and greater credibility attaches to the following report with regard to the efficiency of a Capell fan (diameter, 2½ metres; width, 1·8 metres) erected at the Friedrich Joachim shaft of the Koenigin Elisabeth pit, Essen.

No. of Experiment.	Speed of Engine Revolutions per Minute.	Speed of Fan.	Peripheral Velocity of Fan, Metres per Second.	Actual Depression, h, in Millimetres.	Theoretical Depression, H, in Millimetres.	Volume of Air, Q, Cubic Metres per Second.	Actual Output in Horse-power.	Indicated Horse-power.	Manometric Efficiency.	Mechanical Efficiency.	Equivalent Orifice, a, Cubic Metres.
1	72	274·5	35·93	80	157·9	20·34	21·04	37·61	0·506	55·66	0·8674
2	92	333·0	43·58	112	232·3	29·93	44·51	64·80	0·482	65·74	1·075
3	78	284·9	38·47	93	181·0	22·31	27·56	44·49	0·585	60·19	0·8794
4	96	340·0	44·50	106	242·2	24·51	34·60	58·08	0·44	75·78	0·9058

An electrically driven Capell fan, 3 metres in diameter and 2 metres wide, is in use at the Bonifazius pit, Krey. Each of the lateral intakes is 1·65 metres in diameter. The generating engine, which is fitted with Rider valve gear, has a stroke of 31 inches, and a cylinder diameter of 20 inches. The transmission gear between the electromotor and the fan is twofold, the ratio 1 : 4 being produced in one portion by rope driving, and the ratio 1 : 2 in the other by belt driving. The conducting cable between the dynamo and the electromotor is 1300 metres long, and weighs 1968 kilogrammes.

At a working speed of 200 revolutions for the fan, and with a depression of 58 millimetres in the intake pipe, 40·7 cubic metres of air are discharged per second. The equivalent orifice of the pit $a =$ 2·03 square metres, the pit temperament $\frac{Q^2}{h} = 28·5$.

The useful effect of the fan is . .	31·5 horse-power
The output of the electromotor is . .	43·0 ,,
The output of the dynamo is . .	47·6 ,,
The indicated power of the engine is .	64·4 ,,
Consequently the total mechanical efficiency of the installation is . . .	0·49 ,,

The aforesaid high efficiency of the Capell fan, in cases of an equivalent orifice between 1 and 2 square metres, and with volumes of air not exceeding 40 to 50 cubic metres per second, would presumably diminish in cases of larger equivalent orifices, and with volumes of air up to 100 cubic metres per second, owing to the fact that, in such cases, the internal resistance of the fan would come more into play, and the low, wide flue would not prevent the waste of a good deal of kinetic energy.

Owing to the comparative simplicity of the Capell fan, the cost of installation is relatively low in comparison with other centrifugal fans.

Hoefer's *Mining Engineers' Pocket-Book* gives the following particulars respecting Capell fans:—

SIZE, WEIGHT, PRICE, ETC. OF CAPELL FANS (HOEFER).

Class and Purpose of Fan.	Diameter, Metres.	Speed per Minute, Revolutions.	Volume of Air delivered per Second, Cubic Metres.	Weight of Fan, Kilos. (2·2 lbs.)	Price. £ s.
1. Hand fan, to work as an exhaust, or blower	0·25	...	0·2	38	7 0
	0·35	...	0·33	55	8 15
	0·43	...	0·5	80	10 10
	0·50	...	0·67	100	12 10
2. Small fan for separate ventilation, with attached pneumatic motor. Exhaust or blower	0·43	1500	0·5	90	27 10
	0·5	1200	0·83	150	30 0
	0·65	1000	1·25	270	35 0
	0·75	800	1·67	400	40 0
3. Small fan for separate ventilation, with turbine for a 40-metre head of water	0·35	1600	0·42	...	15 0
	0·43	1400	0·53	...	18 10
	0·50	1250	0·70	...	22 10
	0·65	1000	1·17	...	30 0
4. Fan for main ventilation, with steam engine or pneumatic motor	1·0	450	2·5	1400	85 0
	1·25	425	3·33	1750	115 0
	1·50	400	5·0	2100	140 0
	1·75	375	6·67	2500	180 0
	2·0	350	8·33	3000	215 0

THE SER FAN (Figs. 124*a*, *b*, and *c*).

The Ser fan is very largely used in France, and has almost entirely displaced the large Guibal fans in that country, especially in pits with a small equivalent orifice. Small Ser fans, 20 to 25 inches in diameter, are also largely used for separate ventilation. They are driven by small compressed-air motors, Pelton wheels, turbines, and cost from £48 to £78, including motor.

The Ser fan is fitted with a double intake, with intake cones, and has a large number of vanes (thirty-two and more), curved forwards both inside and out; a spirally widening case and a flared flue are also provided (Fig. 124*c*).

The fan shown in Figs. 124*a* and *b*, measuring 1·4 metre (54 inches) in external diameter, furnishes 12 cubic metres of air per second, when run at a speed of 400 revolutions per minute, in the case of an equivalent orifice 0·5, or 20 cubic metres if the equivalent orifice is 1. The sudden widening of the fan diameter at the end of the vanes, where the spiral delivery chamber commences, must have an unfavourable effect on the efficiency of the fan.

The angle made by the ends of the vanes with the peripheral tangents is 135°, whilst the angle at the base of the vanes (at the intake) is 45°.

According to P. Chalon, the details of the Ser fan are as follows :—

Outside Diameter of Fan.	Equivalent Orifice.	Depression, Millimetre Water-gauge.	Volume of Air discharged per Second.	Speed, Revolutions per Minute.	Motive Power required.	Diameter of Engine Cylinder for a depression of 80 Millimetres.	Stroke of Piston.
metres.	sq. metres.	millimetres.	cub. metres.		horse-power.	metres.	metres.
		50	5	450	7·5		
		65	5·5	500	11	0·250	0·250
1·000	0·25	80	6	560	15		
		50	7	370	10·5		
		65	8	420	16	0·30	0·30
1·200	0·36	80	9	470	19		
		50	9·5	310	14		
		65	11	350	20	0·35	0·35
1·400	0·49	80	12	390	27		
		50	12	365	14		
		65	14	310	25	0·4	0·4
1·600	0·64	80	16	340	36		
		50	16	235	21		
		65	18	270	31	0·45	0·45
1·800	0·81	80	20	300	42		
		50	20	210	27		
		65	22	240	38	0·50	0·50
2·000	1·00	80	25	265	53		
		50	30	165	38		
		65	35	185	58	0·60	0·60
2·500	1·56	80	40	210	80		

It will thus be evident that the capacity of the Ser fan with a diameter of 2½ metres (8 feet) does not exceed 40 cubic metres of air per second. To prevent the working efficiency falling to an excessive degree, the diameter of these fans must be increased to 4½ metres and over when 80 to 100 cubic metres of air per second have to be dealt with.

The Rateau Fan (Figs. 125*a* and *b*, Plate XXVII.).

192. This fan, which is constructed by Bietrix & Co., St. Etienne, to the designs of the inventors, was first used at Cransac, Belgium.

It is fitted with only a single intake orifice, which measures 1·2 metres (47 inches) in diameter. The fan itself (see Figs. 125*a* and *b*) is mounted on the projecting end of the shaft, the two bearings of which are supported by a chair resting on a large block of dressed stone. The bottom of the fan is of conoid form, and may be regarded as describing an arc about the axis of the fan.

At the rim the fan bottom is perpendicular to the axis; and towards

the intake it is prolonged into a conical hood. The conical intake pipe A, connecting the fan with the air way, facilitates the entrance of the air and prevents vortical currents. The thirty vanes are of peculiar shape (see Fig. 125*c*), being of steel, stamped in a hydraulic press, and curved forwards both at the periphery and on the inner edge, just as in the Ser fan. This shape enables the air to enter without concussion, and also increases the rarefactive power (depression) of the fan. The outer edges of the vanes move close in front of the casing which joins the intake pipe. The upper part of the casing is of cast-iron, the lower portion of brickwork. The inner portion of the casing acts as a diffusor for reducing the velocity of the discharged air, whilst, for the same purpose, the outer portion widens spirally towards the flue. This arrangement enables the kinetic energy of the air to be almost entirely converted into pressure.

When an alteration in speed is desired, it can be easily accomplished by changing the driving pulley on the outer free end of the shaft. The principal dimensions of the fan are as follows:—

Diameter of fan	2 metres.
Width at rim	0·16 „
Diameter of intake orifice . . .	1·2 „
Sectional area of same	1·06 square metres.
„ of flue at mouth . .	3·8 „
Diameter of driving pulley . . .	1·0 metre.
Cubical dimensions enclosed by the vanes .	0·75 cubic metre.

The angle made by the vane ends with the radius is 45°.

Experiments made with the Rateau fan show a high working efficiency.

EXPERIMENTS WITH RATEAU FAN, 2 METRES IN DIAMETER.

No. of Experiments	No. of Revolutions per Minute. Of Fan.	No. of Revolutions per Minute. Of Steam Engine.	Depression h.	Velocity of Air Current.	Volume of Air, Q, per Second.	Equivalent Orifice a.	Useful Work in Horse-power.	Indicated Horse-power of Engine.	Mechanical Efficiency.
			mm.	metres.	cubic m.	sq. metres.	horse-pr.	horse-pr.	per cent.
1	290	154	96·75	3·45	13·1	0·50	16·9	30	56·3
2	276	151	101·50	5·14	19·8	0·75	26·8	37·8	70·9
3	215	117	62·75	4·19	16·0	0·77	13·4	22·1	60·6
4	235	128	83·00	6·31	24·0	1·00	26·6	36·8	72·3
5	212	116	68·50	7·08	27·0	1·24	24·6	38·2	64·4
6	196	107	55·75	7·63	28·7	1·47	21·3	37·3	57·1
7	187	102	47	7·73	29·6	1·65	18·6	37·3	49·9
8	184	100	44	7·94	30·2	1·72	17·5	37·8	47·1

In one case the depression was measured in an air way, at a point where the orifice = 2·8 square metres, and the velocity of the current

was not very high. The volume of air discharged was measured at the mouth of the upcast flue, the square mouth being divided into sections by means of fine wires, ten in number, so as to form thirty-six small squares. The velocity was determined by holding the anemometer five seconds in each of these squares, the above results being obtained.

From these tests the following conclusions may be drawn:—

(1) That the Rateau fan can be run at a speed far exceeding 200 revolutions per minute; and that the engine was so constructed that it can work with a steam pressure of 6 atmospheres, and furnish 90 indicated horse-power instead of 38 to 50.

(2) That with a working speed restricted to 200 revolutions, or a peripheral velocity of 20·944 metres, a depression of 36 to 61 millimetres can be produced, the volume of air discharged being 15 to 35 cubic metres when the equivalent orifice is 0·75 to 1·72 square metres.

(3) That the mechanical efficiency (product of volume and depression) is over 50 per cent. of the indicated effect for an equivalent orifice of 0·5 to 1·6, and even 72 per cent. for an equivalent of 1 square metre.

(4) That the construction of the fan is of sufficient strength, and the running even.

(Notwithstanding the above-mentioned advantages of the Rateau fan, the author is privately informed that the experiments made therewith in Maehrisch-Ostrau have furnished reasons for preferring the Geisler fan.)

The following table (p. 193) comprises the results of recent experiments made with Guibal, Ser, Capell, and Rateau fans, the prime cost of each being also included. The item of working expenses applies solely to the fans, and not to the engines as well.

These results also show that the large improved Guibal fans are, in general, still somewhat cheaper than the small fans of Ser, Capell, and Rateau.

The total cost of installing a Guibal fan 12 metres in diameter is about the same, or even a little less, than of a Ser fan 2 metres in diameter and somewhat cheaper than a Capell fan 3·75 metres in diameter, or about the same as a Rateau fan 2·8 metres in diameter, but delivers a larger volume of air under equal conditions as regards equivalent orifice.

Moreover, when the equivalent orifice and volume of air are considerable, the small, narrow, quick-running fans cannot compete with the improved large Guibal fans. The nearest are the larger Giesler fans of $4\frac{1}{2}$ metres diameter and over.

Where electrical power is available, preference will undoubtedly, however, be given to fans of small diameter and high speed, since these latter can be driven better from quick-running motors.

COMPARATIVE TABLE OF GUIBAL, SER, CAPELL, AND RATEAU FANS.

Serial No.	Make of Fan.	Diameter.	Breadth at Rim.	Class of Driving Belt.	Ratio of Speeding up.	No. of Revolutions per Minute.	Depression, Millimetre Water-gauge.	Volume of Air per Second.	Depression at Peripheral Velocity of 35 Metres.	Equivalent Orifice $a=\frac{0\cdot38Q}{h}$	Mechanical Efficiency.	Prime Cost of Fan only.	Prime Cost of Total Installation.	Diurnal Working Expenses of Fan.
		metres.	metres.				mm.	cubic mtrs.	mm.	sq. m.	per cent.	shillings.	shillings.	shillings.
1	Guibal	12	2·5	Direct coupled	...	56	84	64·12	80·8	2·79	52·5	6212	24,800	0·624
2	Guibal	12	2·5	Direct coupled	...	60	104	29·00	91·1	1·07	42·4	5120	24,000	0·640
3	Guibal	9	2·1	Cotton belt	1·6	75	102	32·44	100·0	1·21	50·4	5400	24,720	0·865
4	Guibal	5·8	1·95	Cotton belt	1·6	106	90	49·44	104·1	1·96	60·0	3600	22,400	4·256
Average—												5084	23,975	1·596
5	Ser	1·4	0·24	Leather belt	5·4	391	47	10·34	71·5	0·58	40·5	4800	14,400	0·824
6	Ser	1·6	0·28	Leather belt	4·92	345	68	23·82	96·4	1·08	54·6	6000	16,400	0·960
7	Ser	2·0	0·36	Leather belt	5·3	365	60	41·29	51·8	2·11	44·9	9600	25,600	1·208
8	Ser	2·5	0·45	Leather belt	3·33	154	35	30·92	110·1	1·98	48·0	8292	28,000	2·624
Average—												7173	21,100	1·404
9	Capell	3·75	2·0	Camel hair	4	224	110	42·16	73·7	1·45	63·4	7200	28,800	3·376
10	Capell	2·50	1·8	Rubber	4	200	48	17·35	80·3	0·93	60·8	4200	15,600	1·200
11	Capell	3·60	1·6	Camel hair	4·44	178	72	21·75	76·4	0·95	48·3	6000	27,600	1·680
12	Capell	3·80	1·7	Rubber	5		Results	not for	publication.			8800	32,000	...
Average—												6550	26,000	2·085
13	Rateau	2	0·16	Leather	1·8	177	31	23·10	101·0	1·50	47·3	8400	20,000	3·752
14	Rateau	2	0·16	Leather	2·23	264	81	23·60	131·2	1·03	82·7	7600	20,000	2·608
15	Rateau	2·8	0·23	Leather	4·13	186	72	22·00	120·3	1·02	41·2	9600	24,000	2·560
16	Rateau	2·8	0·224	Leather	1·47	150	52	32·21	136·0	1·67	71·8	11,600	24,000	2·224
Average—												9300	22,000	2·786

THE HANARTE FAN (Figs. 126*a*, *b*, and *c*, Plate XXVII., and Figs. 127*a* and *b*, Plate XXVIII.).

193. The resistance offered to the passage of air through the pit causes rarefaction (loss of pressure), whereas the task of the fan is to propel the rarefied air and compress it before it is able to return to the external atmosphere. According to Hanarte, this re-compression is best effected in a chamber RR and R_1R_1 (Fig. 126*a*) surrounding the fan, in which chamber the air is propelled by the fan, and whence it is discharged into the outer air through an upcast S of progressively diminishing diameter. The outflow from the pipe S is regulated by a reversed conical plug J, which is raised and lowered by means of a small winch and an endless rope. The twelve vanes of the fan are bent to an arc, and their outer ends make an angle of 44 degrees with the tangents of the fan.

To increase the compression in the chamber RR, the fan is usually run in a direction opposite to that taken by the discharged air; nevertheless, the engine is fitted with reversing gear, so that it may be ascertained by trial whether a better effect is obtained by running the fan in the same direction as that taken by the effluent air. For the sake of lightness the vanes are made of thin sheet-metal, corrugated iron (see Fig. 126*b*) having been used, in order to increase the resistance to flexion. The upper compression chamber R_1R_1 can be shut off, when desired, by a sheet-metal cover *vv* and *tt*.

In introducing his fan, Hanarte advanced different points, which we must not pass over in silence. In the first place, he directed attention to the fact that the compression (corresponding to the pit resistance) produced by the suction of the fan is invariably smaller immediately over the top of the upcast shaft than the depression existing in the end of the intake conduit directly in front of the intake orifice of the fan. He cites as an example that a fan set up only about 3 metres away from the shaft, and delivering 33 cubic metres of air per second, produced a depression of 24 millimetres in a niche just above the shaft, whereas the depression at the intake orifice of the fan was 36 millimetres, or 50 per cent. greater than in the first-named position.

Another fan produced a depression of 210 millimetres above the upcast shaft, when delivering 96 cubic metres of air; but close against the intake orifice the depression was 230 millimetres, *i.e.* only 9½ per cent. more than above the shaft, though the length of the air conduit aboveground was greater in this case. Hanarte attributes this to the circumstance that, in the first place, the rarefactive power of the fan was

less in accord with the pit resistance, *i.e.* was far too high. In the second case the relative proportions were more suitable, consequently the second fan must show a far better mechanical efficiency than the first. However, the greater rarefactive power of a fan is primarily dependent on the greater the frictional resistance to be overcome by the air in traversing the channels in the fan. The narrower these channels, *i.e.* the more numerous the vanes, the greater the friction, and consequently also the rarefactive power of the fan, and the lower its mechanical efficiency.

Hence, for instance, the Rieu du Cœur Rateau fan, 2·8 metres in diameter, running at a speed of 186 revolutions per minute, delivering 22 cubic metres of air per second, and producing a depression of 72 millimetres water gauge in the intake conduit, gave a mechanical efficiency of only 0·417, or less than an improved Guibal fan weighing six times as much as the Rateau fan in question. Hence Rateau fans can only give good results in narrow pits with a high resistance, since in fans with thirty vanes the cells are narrow, the fan resistance is high, and will consequently stand in suitable relation with a high pit resistance.

For approximately estimating the fan resistance, in order to institute a comparison with the pit resistance, Hanarte employs the same formula that we have already become acquainted with for measuring the pit, namely, $h = \frac{0\cdot0018LPQ^2}{S^3}$. If now n represents the number of vanes, or cells, in the fan, L the length, P the mean circumference, and S = the mean sectional area of a fan cell, then the fan resistance will be

$$h_1 = \frac{0\cdot0018LP\left(\frac{Q}{n}\right)^2}{S^3}$$

millimetres water gauge. In the case of the Rieu du Cœur Rateau fan, the fan resistance h' was found to be 8·7 millimetres for an output of 22 cubic metres of air per second.

If, as in the Guibal fan, the vanes are few in number, and the cells of large area (consequently the air friction or fan resistance low), then, in order that the fan resistance may be sufficient to overcome the pit resistance and effect the necessary re-compression of the air rarefied in the pit, either the peripheral velocity of the fan must be correspondingly increased, or else vortical currents will ensue within the fan—a circumstance that will naturally lower the manometric efficiency of such a fan.

Hanarte is of opinion that his fans, 1·2 to 2·4 metres (4 to 8 feet) in diameter, are capable of delivering 10, 34, 50, and up to 135 cubic metres of air per second, when working at a speed of 240 revolutions per minute, and dealing with pit temperaments between 6 and 60, or with

equivalent orifices from 1 to 3 square metres. Furthermore, he calculates the diameter D of his fans according to the formula—

$$D = \frac{60\sqrt{g\,\frac{0\cdot38Q}{a}+x}}{\pi n\sqrt{\gamma}} \text{ metres,}$$

wherein Q expresses the volume of air per second, x the increased depression (in millimetres water gauge) produced by the fan, a the equivalent orifice of the pit, $g = 9\cdot81$, n the number of revolutions per minute, and γ the weight of 1 cubic metre of pit air in kilogrammes.

The diameter of the circular effluent orifice d is obtained by the formula—

$$0\cdot9\,\frac{\pi d^2}{4}\sqrt{2gh} = Q, \text{ whence—}$$

$$d = \sqrt{\frac{4Q}{0\cdot9\pi\sqrt{2gh}}} \text{ metres.}$$

Another form of the Hanarte fan, with straight vanes, is shown in Figs. 127*a* and *b*, Plate XXVIII. In this case the flue is widened, in a paraboloid form above and below, like an injector, and can be reduced by means of a double cone J.

The Mortier Fan (Figs. 128*a* and *b*, Plate XXVII.).

194. The Mortier fan is also of the centrifugal type, the action of which depends on the fact that the air forced against the side of the upcast flue is denser, and therefore heavier, than that drawn in at the opposite side. In order to suitably effect this compression the discharge orifice *ab* must be considerably smaller (1 : 1·6) than the intake *cd*, and furthermore, as in the Hanarte fan, the flue must contract up to a certain point, whence it again widens up to the mouth—preferably in the shape of a paraboloid.

In dealing with the Guibal fan (section 164), we have already seen that every other centrifugal fan with central intake also tends to draw in external air at a certain part of the periphery; and this tendency will be intensified when, as is the case with the Mortier fan, the central intake orifice is absent entirely. As a comparison of the Mortier and Hanarte fans (Fig. 126*a*) will show, the principle of the one has been applied to the other; but it remains doubtful whether the widened front portion of the flue in the Hanarte fan increases the efficiency or not. The undoubtedly high output and excellent working of the Mortier fan speaks in favour of the latter. Since there is no obstacle encountered in the centre of the Mortier fan, the vanes must be sufficiently numerous (30 to 32) to set up a resistance, within the fan, corresponding to the pit resistance. According to Wolff, of Essen, the breadth of the vanes

0·13 that of the external diameter of the fan, and the total axial measurement is two-thirds the larger diameter. The vanes are curved in an arc, and so arranged that they make, at the outer ends, an angle of 45 degrees with the tangents, but are radial at the inner ends.

Experience has shown that the maximum useful effect is obtained from the Mortier fan when the air enters with an absolute velocity two-thirds that of the peripheral velocity. Since the movement of the vanes in the upper part of the fan is opposite to that of the entering air, it is found advisable to attach to the side of the casing there a plano-convex core *e*, along the base of which the air can pass freely. The upper dimensions of the flue must be selected in such a manner that the effluent velocity of the discharged air does not exceed 6 to 8 metres per second when the fan is running at normal speed.

On account of its simplicity, lightness, durability, and superior effect to all other fans, the Mortier fan has already come largely into use, and continues to displace other makes. It is also excellently adapted for electric driving, and for separate ventilation, for which latter purpose it can also be driven by compressed air or hydraulic motors.

Up to the present, fans measuring 0·6 to 2·8 metres in diameter have proved sufficient for all purposes, and a peripheral velocity of 51·33 metres per second can easily be obtained, the depression being 228 millimetres. Under these conditions the mechanical efficiency is still 0·6, and the manometric efficiency 0·71.

The following table gives the results of observations made with a Mortier fan, 2 metres in diameter and 1·2 metres wide, at the La Perronière pit in the Loire basin.

OBSERVATIONS WITH MORTIER FAN—2 METRES DIAMETER AND 1·2 METRES WIDE—AT LA PERRONIÈRE COLLIERY.

Number of Revolutions per Minute.		Depression h, Millimetre Water-gauge.	Effluent Velocity of Air Current, Metres per Second.	Volume of Air per Second.	Equivalent Orifice of Pit $a = \frac{0 \cdot 38Q}{\sqrt{h}}$.	Manometric Efficiency.	Indicated Horse-power of Engine.	Mechanical Efficiency.
Engine.	Fan.							
				cubic m.	square m.	per cent.		per cent.
99	238	90	6·300	25·200	1·000	1·108	38	0·786
92	222	65	4·854	19·416	0·915	0·920	25	0·684
110	270	90	4·000	16·000	0·640	0·862	27	0·724

The subjoined table shows the results obtained with Mortier fans, 2·4 to 2·8 metres in diameter, and showing that this fan is unapproached in output by any other centrifugal fan.

EXPERIMENTS WITH MORTIER FANS, 2·4 AND 2·8 METRES IN DIAMETER.

Pit where Tests were made.	Number of Tests.	Dimensions of Fan.		Number of Revolutions per minute.		Depression h, Millimetre Water-gauge.	Volume of Air delivered per Second.	Indicated Horse-power of Engine.	Manometric Efficiency.	Mechanical Efficiency.	Details of Electrical Power at Generating Station.			Equivalent Orifice of Pit.	Remarks.
		Diameter D.	Width b.	Engine.	Fan.										
		m.	m.				cub. m.				volts.	amps.	watts.	sq. m.	
Minister Stein (Eving, near Dortmund).	1	2·8	2·0	110	275	150	88·7	...	0·76	...	...	...	...	2·68	Compound engine; cylinders, 20 and 32 inches diameter; stroke, 26 inches; speed, 110 revolutions per minute.
Do.	2	...	...	108	270	142	91·2	...	0·74	...	...	...	...	2·9	Vertical double-cylinder engine; cylinder diameter, 22 inches; stroke, 24 inches; speed, normal 80, maximum 100 revolutions.
Dahlbusch II., Gelsenkirchen.	1	2·8	1·4	81	283	155	59·9	206	0·73	0·60	...	...	...	1·83	Horizontal, compound, non-condensing engine; cylinder diameter, 21 and 31 inches; stroke, 39½ inches.
	2	...	...	91	318	200	70·0	311	0·755	0·60	...	...	...	1·9	
	3	...	...	100	350	228	76·43	390	0·71	0·60	...	...	...	1·92	
Grimberg shaft, Monopol pit, Camen (Westphalia).	1	2·8	2·0	61·95	260·8	116·3	95·4	272·4	0·657	0·543	...	...	...	3·36	Horizontal compound engine.
	2	...	...	75·2	312·3	172·6	111·93	451·4	0·675	0·5893	...	...	...	3·24	Same dimensions as one preceding.
Bonifacius, Krai (near Gelsenkirchen).	1	2·8	1·2	55	199	78	43·4	...	0·75	0·75	1050	42	44100	1·87	Length of conducting cable, 100 metres.
	2	...	...	55	199	78	43·6	...	0·76	0·76	1050	42	4410	1·88	To produce a depression $h=70$, the Mortier fan required to be run at only 190 revolutions, but the 3-metre Capell fan had to make 218 revolutions. The mechanical efficiency of the latter was 0·5, that of the Mortier fan being 0·75.
Bullerbach shaft of the Government colliery, Deister (Bursinghausen, near Hanover)	1	2·5	1·0	76	344	160	39·12	140·48	0·78	0·78	...	...	...	1·18	Compound condensing engine; cylinders, 14 and 22 inches diameter; stroke, 26 inches.

Main Ventilation by Exhaust versus Compression.

195. Up to now we have considered the ventilating fan, with its motor, as mounted in the immediate vicinity of the upcast air shaft, the fan being connected therewith by a brickwork culvert or conduit, and drawing the air out of the workings by exhaustion. In such event the mouth of the upcast shaft has necessarily to be tightly closed, to prevent direct access of the outer air into the culvert leading to the fan. Provided the upcast, as is most desirable, is used solely for purposes of ventilation, this closing of the mouth can be accomplished without difficulty; and as the fan and its appurtenances can be installed more cheaply aboveground, and are more easily supervised, worked, and repaired in that position, ventilation by exhaust has come to be typical, and in most general use, for the service of pits as a whole.

If, on the other hand, the fan were installed at the intake shaft, and the air blown through the pit, under pressure, the mouth of the intake shaft would have to be closed in a similar manner—a condition attended with much inconvenience, owing to the fact that the intake air shaft serves for winding the won coal, and also for pumping. Consequently, if it be desired to ventilate by compression, or blowing, the fan and motor must be set up on the lowest level of the pit, in the vicinity of the intake shaft, and the steam for the engine must be supplied from boilers at the pit mouth. This, however, causes a loss of heat and power, as well as inconveniently heating the shaft, etc., and consequently this arrangement is only resorted to in exceptional instances.

In pits where there is no danger of explosions of firedamp or coal dust, through ignition by sparks, underground ventilators may be driven by continuous—or alternating—current electromotors.

Generally, however, electric power, as also compressed air or hydraulic power, is only employed for underground ventilators when separate ventilation is in question.

Installing a Guibal Fan for Ventilating by either Suction or Blowing.

196. Guibal and similar fans, that usually work by suction, can also be adapted for blowing by closing the flue (Fig. 129) with a cover p'', and turning the curved slide vv towards the right, thus leaving an effluent aperture open from v to v'. The air culvert A, which usually communicates with the fan intake O, is then closed by means of the slide p', and placed in communication with B by opening a damper p,

so that the air expelled by the fan is delivered through the culvert A into the workings. By opening a door the intake aperture of the fan is put in communication with the outside air, which is then drawn in by the fan.

This arrangement, which is designed for emergency ventilation in the event of an explosion of firedamp or a pit fire, has no particular value, since it is evident that, when the ordinary ventilation has been interrupted through a firedamp explosion, the chief thing to be done is to restore that ventilation as quickly as possible. If there has been no interruption of the air current, but only disturbances resulting from the destruction of brattices, air doors, etc., in the pit, then no intelligent manager would approve of reversing the direction of the current, but would rather use every endeavour to remedy the defects and restore the old order of things with all speed, increasing the ventilation if at all possible.

When deciding on reversing the current, it must also be borne in mind that the natural draught of the pit, hitherto assisting the action of the ventilators, will come into opposition with the latter and weaken its effect.

Tandem Fans.

197. Attempts have been made to introduce in practice a tandem arrangement of ventilating fans, whereby one fan should exhaust air from the pit, leaving to a second fan the task of discharging this air into the atmosphere. This arrangement can easily be demonstrated to be inadvisable, it being preferable to employ a larger single fan, or one running at higher speed, when an increase in the output of air is desired.

Since the depression depends on the square of the peripheral velocity, there is no advantage in this respect from allowing two adjacent fans of equal size and speed to draw from one and the same upcast shaft; and consequently two fans would not draw more air from the shaft than a single one.

The position is different when one fan takes air delivered from another and delivers it into the outer atmosphere. If Q' represents the volume of air discharged by the tandem fans, h' the depression, then $Q'h' = 2Qh$, if Q indicates the volume of air, and h the depression, of a single fan.

$$\text{Hence } \frac{h}{h_1} = \frac{Q^1}{2Q}.$$

Moreover, since—

$$\frac{h}{h^1} = \frac{Q^2}{Q_1^{\,2}}, \quad \text{we thus have—}$$

$$\frac{Q^1}{2Q} = \frac{Q^2}{Q_1^{\,2}}. \quad \text{Hence—}$$

$$Q^1 = \sqrt{2} = 1{\cdot}2599\ Q, \text{ and}$$

$$h^1 = \frac{2Qh}{1{\cdot}2599Q} = \frac{2h}{1{\cdot}2599} = 1{\cdot}587\ h \text{ millimetres.}$$

Consequently the volume of air discharged by the two fans working simultaneously, and driven by engines of equal power, is only 25 per cent. more than from a single fan.

The depression h' produced by the two tandem fans is only 1·587 times that furnished by one alone.

CHAPTER IX.

UTILISING THE VENTILATING CURRENT TO THE UTMOST ADVANTAGE, AND DISTRIBUTING THE SAME THROUGH THE WORKINGS—SPLITTING THE MAIN CURRENT.

ARTIFICIALLY RETARDING THE VENTILATING CURRENT.

198. In ventilating a mine, the object in view should be to obtain the maximum degree of purity of the air, and a suitable temperature (15° to 18° C.) throughout all parts of the workings, so as to enable the miners to discharge their tasks without sustaining any injury to health. Under these conditions, moreover, the working efficiency of the men is maintained at its best. To attain these results, it is first necessary to supply a sufficient volume of fresh air to the workings, and then to distribute it uniformly and as cheaply as possible.

As we have seen (§ 61), it is not a very easy matter to determine beforehand how much air is required to keep the workings in a healthy condition. In very gassy pits as much as 10 cubic metres of air and more may be needed per man per minute, or 5000 to 6000 cubic metres per 1000 tons of coal raised *per diem*, in order to keep the methane content of the pit air down below 1 per cent.

On account of the very troublesome gases from shot firing, the amount of air needed in non-fiery pits is about 5 cubic metres per man, or 1500 cubic metres per minute, per 1000 tons of diurnal output, in order to keep the pit in a suitable condition.

Some "Mining Regulations," *e.g.* those of the Breslau mining district (Ordinance of 18th January 1900), enjoin that the ventilating engines in fiery mines shall be sufficiently powerful to enable the prescribed minimum volume of fresh air to be immediately increased by 25 per cent. when necessary. However, as the following calculations will show, compliance with these regulations may be a rather difficult matter, especially in large mines fitted with good ventilating appliances.

Taking Q as the usual volume of air passed through the pit, then 25 per cent. extra would be 1·25 Q. Setting the value of the

depression for Q as h, that corresponding to 1·25 Q would be $h_1 = 1{\cdot}25^2\, h$, since—

$$\frac{Q^2}{1{\cdot}25^2 Q^2} = \frac{h}{h_1}.$$

Again, expressing the useful power required to furnish volume Q, in ordinary work, as $Ne = \frac{Qh}{75}$ horse-power, the value for Ne corresponding to an increase of 25 per cent. in Q will be—

$Ne_1 = \frac{1{\cdot}25^2 Q_1 h}{75} = \frac{1{\cdot}25^3 Qh}{75} = \frac{1{\cdot}95 Qh}{75}$ horse-power, or, in round numbers, $= \frac{2Qh}{75}$ horse-power. That is to say, an increase of 25 per cent. in the volume of air will necessitate doubling the motive power of the engines.

For instance, if the indicated power of the engine is 125 horse-power, and taking the combined total useful effect of engine and fan as 50 per cent., a 250 indicated horse-power engine will be required to increase the volume of air by 25 per cent. From the numerous reports already cited respecting the efficiency of centrifugal fans, we have seen that this factor very often is no higher than 33 to 34 per cent., especially when large volumes of air are in question, and that consequently no greater useful effect can be counted upon in projecting new installations. Hence, in the eventuality under consideration, a 375 horse-power engine must be provided.

Assuming that doubling the indicated horse-power of the engine is regarded as sufficient, it is generally considered that the power of a compound engine with expansion gear, and usually working at a cut-off of 0·2 to 0·3, can be doubled by merely increasing the admission of the steam. This is true; but why suddenly increase the consumption of steam twofold merely for a quarter of an hour's work?

This question is difficult to answer. Even assuming that the total heating surface available in the boilers is large enough to produce this extra steam, it is impossible to keep the whole of the boilers in constant work solely on the off-chance of a possible firedamp explosion.

Now, provided the ordinary ventilation is sufficiently abundant, there is really no need to increase it in the event of a firedamp explosion if all the appliances already mentioned are present and in good order.

The practical effect of such regulations as are cited above is to compel managers to reduce the ordinary ventilation to a minimum, since, by fixing it on a higher basis and improving the pit temperament, they

would merely increase their own difficulty of complying with the regulations.

The work Ne contained in a ventilating current is, as we have seen, $Ne = Qh$ kilogrammetres per second. Here the volume Q is useful, but the other factor h is burdensome, since the higher the value of h the greater the expenditure of power without any useful result. Hence endeavours will be confined to keeping Q as high, and h as low as possible. The fundamental equation for the volume of air is $Q = Sv$, that is to say, the volume of the air is a product of the sectional area of the air way and the velocity of the current.

It has been already stated (§ 87) that, in order to propel a large volume of air with a low depression, it is necessary to make S large, since, in the formula for the pit resistance, $h = \frac{KPL \times Q^2}{S^3}$, the value of h varies inversely as the cube of the sectional area of the air way S.

The endeavour will therefore be to make the sectional area of the shafts, galleries, etc., traversed by the main current, as large as possible.

However, the practical limit in this direction is soon reached; and besides, the construction of shafts and galleries of large area is considerably more expensive than of smaller ones.

In many cases, cross drivages, drainage galleries, and air ways, in the solid rock, can be kept up for years without any timbering, provided they are not too large in section — thus naturally effecting a considerable saving. Occasionally the rock is so brittle and subjected to such heavy pressure, that it becomes difficult to keep open the haulage and other ways of the necessary dimensions for the work. Hence the endeavour, in such cases, is to avoid making the headings of larger dimensions than are actually necessary. If, however, the galleries have to be kept open, in traversable condition, for a prolonged period, it is well to line them with iron props, etc., or with brickwork, notwithstanding the expense involved.

If, now, instead of increasing the area of the galleries, attempts are made to augment the velocity of the air current, the first result is that the resistance increases as the square of the velocity. Moreover, if the velocity be excessive in any of the working places or galleries much frequented by the men, then inconvenience is caused to the miners. One grave inconvenience attending the employment of high velocity currents is the dispersion of coal dust by the current to considerable distances. Another is, that open lamps are easily blown out, and that in

fiery pits the flame of the safety lamps may be blown through the gauze.

For these reasons, it is inadvisable for the velocity of the air current to exceed 4 metres per second in main cross drivages and drainage galleries. Some authorities prefer that the maximum velocity should be fixed at 2 metres.

INTRODUCING THE MAIN AIR CURRENT INTO AND DISTRIBUTING IT THROUGH THE WORKINGS—SPLITTING THE MAIN CURRENT; REUNITING THE SPLIT CURRENTS AND CONDUCTING THEM TO BANK.

199. The general practice is to convey the incoming air current through one or two shafts down to the lowest level, and thence, when several sloping and parallel seams are present, diverting the split current from the main cross drivage through the various bottom galleries, and through the working places. From these points it ascends to the uppermost level, the so-called air level, where the split currents are reunited, and are finally led through the upcast shaft back to bank.

It may also happen, when there are a number of intermediate levels, that a branch is led off from the main descending current into one of them, then allowed to ascend in the workings, and returned, either through a special air way or the common air way, to the upcast.

This plan of conducting the ventilating current, from below upwards, is advisable, because every air current introduced into the pit, whether in winter or summer, becomes progressively warmed in passing through the workings, hence lighter, and therefore tending to ascend naturally. In fiery mines this tendency is assisted by the light fire-damp liberated from the coal.

For this reason, the employment of ventilating currents flowing in a downward direction is either entirely prohibited by the "Mining Regulations," or only permitted under special precautions. Thus a gallery for conducting such a downward current must be quite smooth in the walls, free from angles and corners, with a gradient not exceeding 10 degrees, and the difference in level between top and bottom must not be over 10 metres (32 feet). Furthermore, the amount of air passing therethrough must be accurately determined beforehand, the number and position of the air doors must be specified, and the whole be carefully and specially supervised.

In large English collieries it is a frequent practice to have three or four parallel air ways, of large section, in place of a single one, for conveying the ventilating current into and out of the workings. This arrangement reduces the pit resistance in a surprising manner; and the practice will have to be extensively imitated elsewhere the further the operations of coal-mining are pushed to greater depths, and the more the burdensome influence of increasing rock temperature makes itself felt in the pit.

In fiery mines and those containing readily inflammable coal with a tendency to spontaneous ignition, it is a fundamental law that the workings should be divided into small sections separated by safety pillars, and each ventilated by a separate current, so that any eventual explosion or pit fire may be confined within narrow limits, and the task of the rescue-parties lightened.

In thick seams, where the preparations for pillar work include the establishment of a number of working sections arranged in succession by inclines along the strike, care is taken, where possible, to ensure that each section has only one means of access to the drainage gallery, and one outlet to the air level. Then, in the event of an outbreak of fire that cannot be promptly extinguished, it is easy to isolate the conflagration, both above and below. For this purpose it is customary to provide recesses in the galleries, and materials for the erection of masonry dams. In distributing the air in the pit it may happen that two currents impinge at right angles, thus producing mutual retardation or even entire nullification, unless some precaution be adopted to divert them laterally (see Figs. 130 and 131, Plate XXVIII.).

Where, in flat seams, two air currents have to cross in the same level without mingling, a crossing, made of well-cemented masonry (Fig. 132, Plate XXVIII.), must be erected at the point of intersection.

Splitting the Main Air Current into Branch Currents.

200. So long as workings were of a simple character, of limited extent, and furnishing merely a small daily output of coal, the air current had only a single way to traverse, and all parts of the pit received the whole current. This, however, soon ceased to be practicable when the development of the workings assumed a more complex character, and consequently the current had to be divided for distribution in the various headings and through the numerous subdivisions of the workings. Now it will be evident that, under certain circumstances, the division of the main current might be effected in a very undesirable and irregular

manner by reason of the different degrees of resistance opposed to the several split currents, the result being that the smaller the resistance in any gallery or section, the larger will be the volume of air passing therethrough. In other words, the air selects the shortest passage, and the one exhibiting the least resistance to be overcome.

This method of distribution, however, usually fails to satisfy the requirements of the pit more or less completely, one section of the mine receiving too much air, another too little. We have thus to face two eventualities—

(1) *The split current is weaker than is necessary and desirable.*—If the individual temperament, or modulus, of a heading or section of the pit be expressed by T_e, then $T_e = \frac{q^2}{h}$. If we have a working place receiving an insufficient amount q of air, then, since $q = \sqrt{T_e h}$, it becomes necessary, in order to increase q, either to augment the air pressure h or the modulus T_e. The only way to increase the local air pressure h is by raising the total pressure H, a procedure accompanied by a corresponding increase, the local pressure h_1, h_2, etc., in all the split currents. Moreover, it is but rarely that the total pressure can be increased without considerable expense, and even then certain sections of the pit would be receiving too much air, or at least more than they did before, or than was designed for them.

The best means of effecting an improvement, therefore, is by acting on the modulus T_e, and increasing its value. Since $h = \frac{q^2 LPK}{S^3}$ and $\frac{q^2}{h} = T_e = \frac{S^3}{LPK}$, then the best way of improving T_e is by increasing the sectional area S, or, should this be impracticable, providing an additional air way near the one already existing. This is generally the only feasible method of effecting an improvement, unless a special source of power be provided for separate ventilation.

(2) *The split current is too strong.*—The remedy for this defect is to simply modify T_e by narrowing the area of the gallery: this will remove a portion of the pressure h, and diminish the volume of air. From the foregoing it will be apparent that, where an air current is split up for ventilating purposes, the necessary depression to be maintained in the main current will depend on the greatest resistance encountered by any of the split currents, *i.e.* by the section exhibiting the smallest modulus. In this section alone will the air be allowed unrestricted passage, whilst the sectional area of all the other receiving branches of the split current must be more or less reduced in accordance with their

resistance, in order that they may not receive more than the proper quota of air. This method entails a certain useless consumption of power, or renders useless a certain portion of the depression, in overcoming the artificially created resistance. This, however, is inevitable.

ARTIFICIALLY RETARDING THE VENTILATING CURRENT.

Air Dams.

201. Two different methods are resorted to for intentionally retarding the ventilating current—one when the current is to be entirely arrested, and the other when, instead of complete suspension, only a portion of the air is allowed to pass.

The former object is accomplished by means of air dams, mostly constructed of well-cemented brickwork. To this class also belong the fire dams for the purpose of cutting off the supply of air to portions of the pit where an outbreak of fire is already in progress or likely to occur. In some instances, to ensure more perfect isolation, these fire dams are made double, with an intermediate space of one or two yards, filled with dry sand. (Not loam, since this cracks in drying, and thus allows air to pass through.)

To thoroughly isolate a sloping section, dams must be erected at the upper and lower ends. In some instances assistance is afforded by plastering the fissured safety pillars with mortar. When fire gases are already escaping from a portion of the field, the operation of dam building may become a very difficult and dangerous task, owing to the poisonous nature of the carbon monoxide present; and in such event it is necessary to make use of the respiration apparatus already described.

Dams of Hay or Straw.

For the rapid closing of a heading in the vicinity of a pit fire, there is nothing better than a dam of hay or straw. This can be erected in the following manner:—A large number of bundles of hay or straw are steeped in muddy water, and then carried as quickly as possible to the proposed site of the dam. There the bundles are quickly piled, one above another, until the dam is complete. When, as is generally the case, injurious gases are present, the men should retreat immediately they have laid down the bundles. In order to purify the air in front of such temporary dam, so as to be able to erect a fire- and gas-proof masonry dam, a hand-power fan is placed in a suitable position, and the air delivered through tubbings to the site of the dam.

Such hay and straw dams are decidedly preferable to the portable rubber dam recommended by Wagner for the same purpose, since they are cheaper and always readily constructed. (The Wagner portable dam is described in Lamprecht's *Recovery Work after Pit Fires.*[1])

A gallery can be quickly closed by means of a boarded dam, formed by nailing boards on to the upright timbers, so as to overlap as shown in Fig. 133, and then plastering the whole over with ordinary or cement mortar. The mortar sticks better when the boards have been coated with tar—an operation best performed aboveground.

Dams of Pit Timbers.

Fairly air-tight and durable dams can be constructed of old pit timbers cut into 3 to 4 feet lengths and piled up in a part of the gallery where the roof, walls, and floor are fairly even. The interstices are then filled up properly with dry sand.

Obstructions for Regulating the Flow of Air.

202. In galleries and cross drivages which are used for passages or haulage ways as well as for ventilation, the only feasible methods of interrupting and stopping the ventilating current are such as permit the passage of persons or trucks from time to time, *i.e.* can be opened and closed again. The erection of similar obstructions at certain parts in the pit is also necessary for the purpose of splitting the ventilating current, in order that each split current may receive its proper quota of air.

For this purpose use is made of air curtains and air doors.

(1) *Air curtains.*—Partial isolation can be effected by suspending one or more curtains of coarse tarred canvas in succession across the gallery. This does not present any hindrance to the work of haulage, the curtain being merely pushed aside or raised, and then returning into position of its own accord. However, though simple, these curtains are not very effective.

(2) *Air doors.*—These are used in large galleries. When merely intended to check, and not entirely obstruct, the air current, these doors are often erected in a very rough manner. The doors are hung on frames, the sill timbers of which must be embedded in the floor when the gallery is used for haulage. The doors themselves are made of boards or planks, with two cross pieces, a diagonal strut, and two hinges

[1] Published by Scott, Greenwood & Co.

for hanging the door on hooks. The whole is coated with a mixture of burnt lime and soft curd. The direction in which these doors open is invariably against the air current, so that the latter exhibits a constant tendency to force them to again. Furthermore, the door frame should always be set a little aslant, so that the door will close with its own weight. (See Figs. 134*a* and 134*b*, Plate XXVIII.). If the air door be provided with a damper slide, to allow the passage of a definite volume of air, then, in fiery mines, this slide should be as near the roof as possible, in order to prevent the accumulation of inflammable gases, and the consequent risk of an explosion.

A tentative setting of the slide will enable one to judge when the right amount of air is passing through the opening. Air doors are somewhat of a hindrance to the work of haulage; the inconvenience arising from the opening and shutting of the doors being, however, greater in one direction than the other. Thus, since the doors close of themselves in the direction of the air current, all that is necessary to open them in the opposite direction is to push, the closing being effected automatically as soon as the last truck has gone by.

When, however, the trucks are moving in the opposite direction the doors have to be held open until the last truck has passed through. As a rule, where the traffic is brisk, a boy, or an invalided miner, is stationed at the door to open and close it as required. Should the air current suffer excessive disturbance through the necessity of keeping the door open for long, it is usual to set up a second door at such a distance from the first that a whole train of trucks can be conveniently accommodated between them, so that the one door can be closed while the other is held open. Cords running over pulleys can also be employed to facilitate opening and closing the doors.

In fiery pits the air doors are usually situated in the intake galleries, *i.e.* the haulage ways, drainage galleries, etc., supervision being easier there, and also because then no hindrance is presented to the escape of the air to the upcast when strongly impregnated with firedamp. Otherwise, the air doors are less obstructive to the work of haulage when placed in the return galleries.

In haulage ways with double tracks the air doors are made in two wings, each of which opens in the direction in which the trucks on that side are travelling.

Where the shafts are arranged centrally, *i.e.* the intake and upcast shafts close together and connected by short headings, these connecting ways must be kept closed by means of specially tight and firm doors in order to prevent the air making a short cut from one sha't to the

other. In such cases it is usual to set up three doors, one behind another, the frames of which are let into the walls of the gallery, and well bricked round.

Not infrequently the doors and frames are made of iron, to prevent their destruction in the event of fire.

Rescue or Safety Air Doors.

203. When an explosion of firedamp occurs, the existing air doors are very often thrown down, partly or entirely, and destroyed; the consequence being that, even when the ventilating machinery has remained uninjured or can be quickly restarted, the air current does not take its way through the workings that are filled with afterdamp and poisonous gases. It has already been mentioned that the first task of a rescue-party entering the pit under such circumstances is to repair the damaged doors and clear away any falls and débris likely to obstruct the air current, in order that the rescue work may be brought to a successful issue.

In order to prevent the deviation of the air current from its proper direction through the destruction of the air doors, it has been proposed to set up reserve air doors in the near vicinity of the ordinary doors (see Figs. 135*a* and 135*b*, Plate XXVIII.); and in some places this practice has actually been adopted.

In Fig. 135*a*, A indicates the ordinary air door for closing the gallery, whilst B represents a reserve or safety door situated at the roof of the gallery. The frame of the ordinary door *aa* is mounted in an iron frame *bb*, which is let into the rock so as to be uninjured by any explosion of firedamp that may occur. On the side nearest the workings, and from whence the effects of a gas explosion may be expected to manifest themselves, a recess is sunk in the roof of the gallery, and in this is placed a horizontal frame *bb*, surrounding a reserve door B, which is pivoted at *d*. This door B, when released, will naturally turn on its support and assume a vertical position, through the descent of the free end. To prevent this at ordinary times the free end is retained by an iron bar *r*, which can be shot to and fro in a socket, the lower part of the bar being shaped as a rack, engaging with a pinion *e*, to the axis of which is attached a counterpoised lever *g*. As a general thing, the bar *r* engages behind a nose-piece *i* on the safety door, and keeps the latter in its horizontal position; but, in the event of an explosion, accompanied by a powerful concussion of air which throws down the ordinary door A, the reserve door B will also be lifted thereby, whereupon the counterpoise *g* will descend,

thus drawing back the bar r, and allowing the safety door to fall down into the place hitherto occupied by the ordinary door.

Similar emergency doors have been erected in Westphalia, Austria, and other mining districts, and are reported to act well in cases of explosion.

THEORY OF THE MODULUS, OR INDIVIDUAL TEMPERAMENT, OF DIFFERENT PORTIONS OF A PIT.

204. The distribution of the split portions of the main air current through the various parts of the workings is, as we have already seen, dependent on the resistance, modulus, or individual temperament of the latter.

In each pit there is one free current, without air doors, in the path traversed by which current is found the greatest resistance, and which determines the depression under which the whole ventilation has to be effected.

The raising of this depression has to be continued until the amount of air required by the pit is reached. Under ordinary conditions, this is the current traversing the longest distance through the workings; since, other circumstances being equal, the temperament depends on the length of gallery traversed. Now, as the longest current has the greatest pressure, it follows that all the other split currents, with lower resistances, would receive more than their proper quantum of air, unless throttled. A second current of equal length and resistance to the first may, however, be present in the pit; in which event this one, too, will be left free. Speaking generally, it may be said that the arrangement of split air currents should be so managed, and the length traversed in each case so contrived, that the resistance or modulus is approximately the same in all. If this be successfully accomplished, the total resistance of the pit will also be reduced to a minimum.

When the individual temperaments have been determined, they can then be compared, and afford a basis for the establishment of rules for the appropriate distribution or splitting of the air current.

Two eventualities may be set down—

I. Take the case where the current traverses various working places and galleries in succession. In such event it will be possible to establish, for the various successive portions, a modulus, which one may regard as "additive," since it is the result of the addition of the individual moduli.

II. In this case the main current from the intake shaft is divided at a certain point into two or more split currents, which are subsequently reunited. Here the total modulus is to be determined.

First eventuality, the additive modulus.

Assuming there are three galleries or divisions of the pit in question, and that these are traversed in succession by the same current; and, finally, that they should exhibit the individual moduli t, t' and t'' (Fig. 134, Plate XXVIII.):

The same volume of air q traverses all three galleries, g, g', and g''.

In the first gallery g the value of t is $\frac{q^2}{h}$

„ second „ g' „ $t' = \frac{q^2}{h'}$

„ third „ g'' „ $t'' = \frac{q^2}{h''}$, whence it follows that $h = \frac{q^2}{t}$, $h' = \frac{q^2}{t'}$, and $h'' = \frac{q^2}{t''}$.

The general or additive modulus T_a is therefore $\frac{q^2}{h+h'+h''}$.

On replacing h, h', and h'' by the corresponding values, we have—

$$T_a = \frac{q^2}{\frac{q^2}{t}+\frac{q^2}{t'}+\frac{q^2}{t''}} = \frac{t \times t' \times t''}{t \times t' + t' \times t'' + t \times t''}.$$

The additive modulus of the three galleries or divisions of the workings traversed in succession by the same current is therefore the product of the individual moduli, divided by the sum of their combinations.

Second eventuality, the total modulus.

Assuming, once more, the presence of three galleries g, g' and g'', which start from the same point a, and are reunited in the gallery b (Fig. 135, Plate XXIX.):

The volume A of air entering the gallery a is distributed among the three galleries g, g', g'', so that $Q = q+q'+q''$. If t, t', and t'' represent the individual moduli of the three galleries g, g', and g'', then—

$$q = \sqrt{th}$$
$$q' = \sqrt{t'h}, \text{ and}$$
$$q'' = \sqrt{t''h}, \text{ and } q = \sqrt{T_g h} = q+q'+q''.$$

On replacing q, q', and q'' by the corresponding values, we have: $\sqrt{th}+\sqrt{t'h}+\sqrt{t''h} = \sqrt{T_g h}$, and $\sqrt{th}+\sqrt{t'h}+\sqrt{t''h} = \sqrt{T_g h}$ or $T_g = (\sqrt{t}+\sqrt{t'}+\sqrt{t''})^2$.

Hence the total modulus T_g is equal to the square of the sum of the roots of the individual moduli.

Example—

205. Assume the galleries and workings in a pit to have the

arrangement displayed in plan in Fig. 138*a*, and as a sectional elevation in Fig. 138*b*. P is the circular winding and intake shaft, 4 metres in diameter, and P′ the upcast shaft, of the same diameter. AB is the main cross drivage, intercepting the upper seam at B and the lower seam at *D*. In the western drainage gallery B*v*, a rising drive *um* starts from the point *u*, and branches into a middle gallery *mz* at the point *m*, owing to the portion of the upper seam to the west of *vx* having been found unworkable. From the point *v*, where the first seam again becomes workable, a rising drive was made to connect *vx* with *xz*, and then a longwall heading was driven into the field. The rising drive *zy* serves for working a second longwall heading, which it also connects with the air level *y*E. From this latter the air way EF conducts the western air current to the upcast shaft *P′*.

BG is the eastern drainage gallery in the No. I. seam, out of which the rising drive GH, with its appurtenant working places, extends eastward into the field. HE indicates the upper air way, which conveys the air back from this portion of the workings to the main cross air way leading to the upcast shaft.

DL is the eastern drainage gallery in No. II. seam, whence is driven the working gallery LM, the upper end of which is connected with the upcast by the air way MF.

As will be seen from the plan, the main current is split at B into three branches, the western one of which flows through the two western longwall galleries *vx* and *zy* in the upper seam; the second traversing the eastern longwall gallery in the first seam; whilst the third branch ventilates the eastern longwall gallery in the lower seam. The western current in the first seam divides at *u* into two, which are reunited at *z* and pass away together.

Particulars of the Galleries, etc. in Figs. 136*a* and 136*b*.	Dimensions. Height or Diameter.	Dimensions. Width.	Circumference P.	Sectional Area S.	Cube of Sectional Area.	Length of Headings and Depth of Shafts.	Modulus $t = \frac{LPK}{S^3}$ K = 0·0017 for Headings, and K = 0·001 for Shafts.	Serial Denomination of Moduli.
	metres.	m.	metres.	sq. m.	sq. m.	metres.		
Cross drivage AB	2·00	2·0	8	4	64	1500	2·9629	t_1
Western drainage gallery B*u*	1·50	1·6	6·2	2·4	13·824	1000	1·2387	t_2
Gallery *umz*	1·00	1·0	4·0	1	1	800	0·1736	t_3
,, *uvxz*	1·0	1·0	4·0	1	1	1000	0·1390	t_4
,, *zy*E	1·5	1·6	6·2	2·4	13·824	1000	1·2387	t_5
Air way EF	2·0	2·0	8	4	64·0	200	22·222	t_6
Gallery BGHE	1·5	1·0	5	1·5	3·375	1600	0·2344	t_7
Cross drivage BD	2·0	2·0	8	4	64·0	200	22·222	t_8
Gallery DLMF	1·50	1·0	15	1·5	3·375	2200	0·1704	t_9
○ shaft P	4	...	12·57	12·57	1·986	500	316·0098	t_{10}
○ shaft P[1]	4	...	12·57	12·57	1·986	450	351·122	t_{11}

The preceding table gives the dimensions and moduli of the various headings mentioned in the example and shown in the Figures. These particulars enable the additive and total moduli to be estimated.

No. I. Seam. The shaft P and cross drivage AB, which are in mutual communication, furnish an additive temperament—

$$P+AB=T_a=\frac{t_{10}+t_1}{t_{10}\times t_1}=2\cdot9338.$$

At the point B we have—

(1) The set of galleries in the western field, consisting of three galleries in succession, namely, the drainage gallery B*u*, the headings *umz* and *zy*E, the additive temperament of which is to be ascertained.

$$Bu+umz+zyE+T_a{}^1=\frac{t_2\times t_3\times t_5}{t_2t_3+t_2t_5+t_2t_5}=$$

$$\frac{1\cdot2387\times0\cdot1736\times1\cdot2387}{(1\cdot2387\times0\cdot1736)+(1\cdot2387\times1\cdot2387)+(0\cdot1736\times1\cdot2387)}=0\cdot1356.$$

(2) The galleries to the east of the cross drivage in the first seam. $BG+GH+HE=T_a''=t_7=0\cdot2344.$

These two sections of the pit furnish a common current and the total modulus $T_c=(\sqrt{T_a'}+\sqrt{T_a''})^2=(\sqrt{0\cdot1356}+\sqrt{0\cdot2344})^2=0\cdot72657.$

These two sections are followed by the air way EF, with the modulus $t_6=22\cdot222$. On uniting the total modulus T_c of the two sections in the first seam and the modulus t_6 of the air way EF, we obtain the additive modulus $T_a{}^3$ of the first seam, from the intake shaft P to the foot of the upcast shaft.

$$\text{This is: } T_{a3}=\frac{t_6\times t_c}{t_6+t_c}=\frac{22\cdot222\times0\cdot72657}{22\cdot222+0\cdot72657}=0\cdot7035563.$$

No. II. Seam. The workings in this second seam consist of the extension BD of the main air way AB and the galleries DMLF, which furnish a total modulus—

$$BD+DMLF=T_{a4}=\frac{t_8\times t_9}{t_8+t_9}=\frac{22\cdot222\times0\cdot1704}{22\cdot222+0\cdot1704}=0\cdot1691.$$

This is the modulus of the second seam. (The value, however, is evidently too low.)

The temperament of the workings in both seams, up to the foot of the upcast shaft, can be deduced from T_{a4} and T_{a3}. Between B and F in the first seam there are two currents, the modulus of which, T_c, is known.

Since the currents from both seams unite at the upcast shaft, they form a total modulus $T_{c1}=(\sqrt{T_{a3}}+\sqrt{T_{a4}})^2=(\sqrt{0\cdot7035563}+\sqrt{0\cdot1691})^2$ $=T_{c1}=1\cdot5635.$

To now find the temperament of the whole pit, it is necessary to add to the value T_{c1} the temperaments of the winding shaft P, the air way AB, and the winding shaft P_1. This furnishes the total additive modulus, or temperament, $T_z = \frac{T_a \times t_{11} \times T_{c1}}{T_a \times t_{11} + T_{c1} t_{11} + T_{c1} T_a} =$

$$\frac{2{\cdot}9338 \times 351{\cdot}122 \times 1{\cdot}5635}{2{\cdot}9338 \times 351{\cdot}122 + 1{\cdot}5635 \times 351{\cdot}122 + 1{\cdot}5635 \times 2{\cdot}9338} = 1{\cdot}017.$$

On now selecting any desired pressure for propelling the air through the pit, we obtain a volume of air depending on the temperament and distributable through the various parts of the workings.

For instance, assuming the depression $h = 80$ millimetres water gauge, then the volume of air for the whole pit will be: $Q = \sqrt{T \times h} = \sqrt{1{\cdot}017 \times 80} = 9{\cdot}02$ cubic metres per second.

The modulus of each of the various divisions of the workings being known, the distribution of the volume Q can be ascertained by determining the pressure of the air in each.

The amount of this individual pressure h_0 consumed in each division will be $h_0 = \frac{Q^2}{t_0}$, that is to say, equal to the square of the traversing volume of air divided by the temperament.

For the winding shaft P and the cross drivage AB we have—

$$h_1 = \frac{Q^2}{T_a} = \frac{2{\cdot}9338}{9{\cdot}02^2} = \frac{81{\cdot}36}{2{\cdot}9338} = 27{\cdot}73 \text{ millimetres,}$$

For the three currents in the two seams to the upcast shaft—

$$h_2 = \frac{Q^2}{T_{c1}} = \frac{81{\cdot}36^2}{1{\cdot}5635} = 52{\cdot}04 \text{ millimetres,}$$

For the upcast shaft P′ we have—

$$h_3 = \frac{Q^2}{t_{11}} = \frac{81{\cdot}36}{351{\cdot}122} = 0{\cdot}23 \text{ millimetre.}$$

Thus the pressure for the whole pit is—

$$\begin{aligned} h_1 &= 27{\cdot}73 \\ h_2 &= 52{\cdot}04 \\ h_3 &= 0{\cdot}23 \\ \hline \text{Total} &= 80{\cdot}00 \text{ millimetres,} \end{aligned}$$

as assumed above.

The modulus and air pressure of each of the two seams being known, the distribution of the available 9·02 cubic metres of air can now be determined.

For the upper seam the volume of air is—

$$q_1 = \sqrt{T_{a3} \times h_2} = \sqrt{0{\cdot}7035563 \times 52{\cdot}04} = 6{\cdot}05 \text{ cubic metres per second.}$$

For the lower seam—

$$q_2 = \sqrt{T_{a3} \times h_2} = \sqrt{0.1691 \times 52.04} = 2.97 \text{ cubic metres.}$$

Consequently $q_1 + q_2 = 6.05 + 2.97 = 9.02$ cubic metres.

Since, in the upper seam, there are two sets of workings, each with a separate air current, the volume of air distributed to each must be ascertained. The depression h_4 in these two divisions is equal to the depression h_2, already determined, less the amount of pressure consumed in the air way EF, hence—

$$h_4 = h_2 - \frac{q^2}{22.222} = 52.04 - \frac{6.05^2}{22.222} = 50.4 \text{ millimetres.}$$

Consequently the volume of air in the western division of the upper seam will be—

$$q_3 = \sqrt{T_{a1} \times h_4} = \sqrt{0.1356 \times 50.4} = 2.61 \text{ cubic metres per second.}$$

In the eastern portion of the upper seam the volume of air supply will be: $q_4 = \sqrt{t_7 \times h_4} = \sqrt{0.1356 \times 50.4} = 3.44$ cubic metres.

It may frequently happen that the above-calculated distribution of air in the various sections of the workings will not prove suitable, and an alteration becomes necessary.

Assuming that the given volume of air, 9·02 cubic metres, is desired to be allocated in the following manner—

To the western field of No. I. seam	= 3·6	cubic metres.
" eastern " "	= 3·0	"
To No. II. seam . .	= 2·42	"
Together . .	9·02	cubic metres.

As we have seen, there are two methods of increasing the volume 2·62 cubic metres in the western division of No. I. seam to 3·6 cubic metres: either by increasing the pressure h to a suitable extent, or by improving the modulus $t_3 = 0.1736$ of this division. Now, the former method would entail an increase in the air supplied to the other divisions of the workings as well, and a corresponding increase in the consumption of motive power.

Hence it will be preferable to seek for a means of improving the modulus of the division in question. A way of splitting the air current at the point u is shown in Fig. 138*a*, Plate XXIX. Here the drainage gallery Bu is prolonged westward through the unworkable part of the seam, a new rising drive vx being started at v (where the seam again improves), and connected with zy. According to the table already given, the section $uvxz$ has the modulus $t_4 = 0.1390$; so that by uniting this value with that of the branch umz we obtain a total

modulus applicable to the western division of No. I. seam. This total modulus is—

$$T_{c2} = (\sqrt{t_3} + \sqrt{t_4})^2 = (\sqrt{0.1736} + \sqrt{0.1390})^2 = 0.6233.$$

In consequence of this modification the new modulus T_{aa} of the western division, from B to E, has to be determined. This is done by the equation—

$$T_{aa} = \frac{t_2 T_{c2} \times t_5}{t_2 \times T_{c2} + t_2 \times t_5 + T_{c2} \times t_5} =$$

$$\frac{1.2387 \times 0.6233 \times 1.2387}{1.2387 \times 0.6233 + 1.2387 \times 1.2387 + 0.6233 \times 1.2387} = 0.3106.$$

Now, Ta' has already been found $= 0.1356$; so that, if we seek the volume of air qn_3, that will be obtained under the depression 80 millimetres, and the improved temperament 0.3106, we find—

$$qn_3 = q_3 \times \sqrt{\frac{T_{aa}}{T_{a1}}} = 2.61\sqrt{\frac{0.3106}{0.1356}} = 4 \text{ cubic metres.}$$

The desired volume being only 3.6 cubic metres, we have here an excess of 4 to 3.6 = 0.4 cubic metre, which, however, will generally be desirable.

Nevertheless, if it be considered essential to keep the volume of air down to the limit of 3.6 cubic metres, this object can be accomplished by reducing the depression of 80 millimetres, since the division in question is also that exhibiting the maximum resistance, or lowest temperament, and therefore decisive for the entire pit. Since the depression varies as the square of the volume of air supplied, the amended depression will be—

$$h_x = 80\frac{3.6^2}{4^2} = 64.8, \text{ or, in round numbers, 65 millimetres.}$$

It is also easy to calculate the volume of air that would pass through the other sections of the workings at this depression of 65 millimetres.

When the depression is 80 millimetres, the eastern division of the No. I. seam receives 3.44 cubic metres; hence, with the depression 65 millimetres, the volume would be $\frac{80}{65} = \frac{3.44^2}{x^2}$, *i.e.* $x = 3.1$ cubic metres.

Similarly, the second seam would receive only $\frac{80}{65} = \frac{2.97^2}{x^2}$, *i.e.* $x = 2.7$ cubic metres.

The eastern division of No. I. seam and No. II. seam receive a larger volume of air than was originally contemplated. This is generally highly desirable; nevertheless, it may in some cases be advisable to prevent this excess, and in such event the intake aperture must be regulated by means

of a sliding damper, the dimensions of the new aperture then being also a matter for calculation.

CALCULATING THE ORIFICE OF THE AIR SLIDE IN BRATTICES.

206. The task to be performed is the nullification of a portion of the pressure by resistance, and is accomplished by reducing the aperture in the air slide.

Let us take the case of a heading through which passes a given volume of air Q, so long as there is no obstruction, the modulus of this heading being of known value, t. Hence the depression is $h = \frac{Q^2}{t}$. If now it be desired to diminish the volume Q to q, then the depression h will have to be reduced to h', and h' will $= \frac{q^2}{t}$.

If we set down $h - h' = h''$, then $h'' = \frac{Q^2 - q^2}{t}$.

In order to consume the excess pressure, the latter must be converted into velocity by the aperture in the air slide. This theoretical velocity is: $v = \sqrt{2gh''} = 4{\cdot}33 \sqrt{h''}$.

Assuming further that the flow of air takes place through a thin partition, the coefficient of contraction being $C = 0{\cdot}66$, the actual effluent velocity will then be: $v' = 0{\cdot}66v$, or $v' = 0{\cdot}66 \times 4{\cdot}43 \sqrt{h''} = 2{\cdot}92 \sqrt{h''}$.

The pressure h'' is here given in millimetre water gauge, and must be divided by the average weight of a cubic metre of pit air, namely, 1·33 kilometres.

Hence we have—

$$v'' = 2{\cdot}92\sqrt{\frac{h''}{1{\cdot}133}} = 2{\cdot}92\sqrt{\frac{1}{1{\cdot}133}} \times \sqrt{h''} = 2{\cdot}74 \sqrt{h''}.$$

If the sectional area of the slide $s = \frac{q}{v''} = \frac{q}{2{\cdot}74 \sqrt{h''}}$, and h'' be replaced by its value $\frac{Q^2 - q^2}{t}$, we then have—

$$s = \frac{q}{2{\cdot}744\sqrt{\frac{Q^2 - q^2}{t}}}$$

as the formula for determining the aperture of the slide.

In this case it is presumed that the values of the modulus of the pit section, previous volume of air admitted, and the volume

passing through subsequent to the erection of the air door, are all known.

If, for the sake of simplicity, we adhere to the example selected above—though the volumes of air therein determined are evidently very small, owing to the restricted dimensions of the headings—we have a volume $Q = 3·6$ cubic metres, for the air supply to the eastern division of No. I. seam, under the depression 65 millimetres; and a temperament for this section $t_7 = 0·2344$. If now q is not to exceed 3 cubic metres, the aperture in the air slide must have an area of—

$$s_1 = \frac{3}{2·74\sqrt{\frac{3·6^2 - 3^2}{0·2344}}} = 0·253 \text{ square metre.}$$

The values for the second seam would be $Q_1 = 2·7$, and $T_{a4} = 0·1691$. If, in this case, the volume of air supplied is to be only $q_1 = 2·4$ cubic metres, then we have—

$$s_2 = \frac{2·4}{2·74\sqrt{\frac{2·7^2 - 2·4^2}{0·0191}}} = 0·292 \text{ square metre.}$$

Were the above volume of 3·6 cubic metres of air to be supplied to the western portion of the No. I. seam by increasing the air pressure, instead of by splitting the current, the first question would be how far the original pressure of 80 millimetres would have to be augmented in order to furnish 3·6 instead of 2·61 cubic metres of air.

The original pressure h being 80 millimetres, this increase would be

$$h' = 80\frac{Q^2}{q^2} = 80 \times \frac{3·6^2}{2·61^2} = 152·2 \text{ millimetres water gauge.}$$

At this pressure the total energy consumed in propelling the entire current would amount to: 9·02 cubic metres $\times$ 152·2 = 1372·84 kilogrammetres per second = 18·3 horse-power, instead of the 9·02 $\times$ 80 = 721·6 kilogrammetres per second = 9·6 horse-power originally used. Assuming the efficiency of the motor and fan to be 33·3 per cent., the actual power required for driving the fan would then be 18·83 $\times$ 3 = 54·9 horse-power, in place of the original 28·8 horse-power.

As soon as the full particulars for determining the individual temperaments have been collected in the pit—the determinations entailing care, but not strict or rigorously minute accuracy—the moduli can be calculated and added together, thus finally giving the total temperament of the entire pit. In most instances an insufficient distribution of air will be found to prevail; and hence the current will have to be split, or resistances introduced in certain parts.

When any section of the pit is insufficiently ventilated, owing to the

depression *h* or the individual modulus being too low, it will be necessary to investigate which of these two factors can be suitably modified. Whenever possible, the modulus should be increased by splitting the current, thereby diminishing the total expenditure of work. Of course, when this is impractical, the total pressure *h*, and therefore the total expenditure of energy, will have to be increased.

CHAPTER X.

VENTILATING PRELIMINARY WORKINGS—BLIND HEADINGS—SEPARATE VENTILATION—SUPERVISION OF VENTILATION.

207. It often happens that preliminary headings that are not as yet in communication with other workings cannot be ventilated in the ordinary way. In this case we have so-called blind headings, in which the air current is obliged to return in the same direction as it entered. This is usually the case in shaft sinking, and in driving cross drivages, drainage galleries, and inclines. In these places natural ventilation by diffusion is confined to very short distances or depths; and in order to produce a circulation of air it is necessary to provide two separate passages—one for leading the air into the working place, the other for conducting it back to the starting-point again.

The ventilation of such blind galleries is classed along with the main ventilation, or as separate ventilation, according as the force for propelling the air is derived from the main current or furnished by a source of power specially installed at the commencement of the branch.

The complete separation of the ingoing and returning air, and the provision of two independent air ways, is effected by means of brattices, parallel headings, and air tubbing.

BRATTICES.

208. The simplest method of forming a double air way in a gallery or heading is by erecting an air-tight wall, with air door in the main air way (AB, Fig. 139), at the entrance of the blind heading (CD), and diverting the current by means of a brattice, forming the continuation of this wall, so that the air enters the heading on one side of the partition thus formed, and returns along the other side. For short distances, up to 10–20 yards or so, the brattice may be made of tarred canvas, instead of a fixed partition.

A vertical brattice may be constructed of a row of timbers, on which are nailed a series of boards planed at the edges so as to fit closely

together. The interstices between the boards are best filled up with dry sand. In the case of very wet headings, well-pugged clay or loam may be used instead, since there is here no fear of the clay cracking and allowing air to leak through.

Brattices may also be made of brickwork combined with woodwork, vertical pillars being set up on sills, at a distance of 4–4½ feet apart, and connected by horizontal beams 3–4 feet apart. The spaces between the pillars and the beams are filled with brickwork (half-brick thick), set in reduced cement mortar (lime and sand), mixed with cement in the proportion of 1 part to 3 parts of the lime. The brickwork is faced with a coating of the same mortar, preferably on a layer of tar.

Very high brattices, intended to last a long time, are preferably constructed entirely of cemented brickwork, one brick thick. It is inadvisable to erect buttresses 3–4 yards apart in such brattices, owing to the resulting increased resistance to the passage of the current. Horizontal brattices are mostly used in places where the dimensions of the gallery, etc. do not permit the erection of those of vertical type, and where water has to be drained off. They are made by laying joists across the heading and covering these with planks (see Figs. 140 and 141), or else a flat arch is constructed, preferably with shaped bricks, above the watercourse, as shown in Fig. 142.

In the case of horizontal brattices, the return flow of air invariably traverses the lower division of the gallery, in order that it may be facilitated by the water running in the same direction. Where a shaft has to be bratticed, in order to act as both intake and upcast, special care is necessary in making the brattice air-tight, so as to prevent waste of air by leakage. The usual form of brattice for shafts is a single or double partition of boards, a brickwork partition of the necessary thickness (one brick) occupying too much room.

Attempts have, however, been made to replace wood by sheet-iron for shaft brattices, owing to the danger of wooden brattices, especially where the shaft contains steam pipes, since the vicinity of a steam pipe and uninterrupted contact with escaping steam renders the wood as inflammable as tinder. This modification is attended with difficulty, as regards the establishment of air-tight joints between the separate sheets; and the latter are also liable to rapid corrosion by rust, unless very thick. Apparently the best solution of the problem is afforded by reinforced concrete, of the Monier type, the brattice being constructed of wire netting covered on both sides with a (smooth-faced) layer of cement concrete.

As we have seen, the effect of a brattice is to divide the heading into

two compartments, the additive modulus of which new circulation has to be determined. If, as is sure to be the case, the determinative factors (length and sectional area) furnish a reduced modulus for the new order of things, there results a high resistance which leads to the depreciation of the modulus of the whole section. Consequently the air pressure must be increased to enable the previous supply to be maintained. This solution will evidently increase the total expenditure of force consumed in ventilating the whole pit, and is therefore not very commendable. True, if the blind heading is one of large diameter, so that the orifice of the air passage is of considerable dimensions, the modulus will be smaller; but in this case the diminution is not a matter of such great importance. These conditions, however, do not usually obtain. Frequently, in order to provide room for a haulage track in one part of the heading, the brattice has to be set up closer to the one wall, as in Fig. 143. This procedure, however, naturally increases the resistance considerably.

In many instances it will be found preferable to divert only a portion of the main air current, instead of the whole, into such blind galleries, as in Fig. 144, leaving the main current to pass straight on its way.

In such cases it will of course be necessary to previously determine exactly the temperaments of the blind heading and other parts of the workings, as was done in the example cited in § 205, in order to decide whether it is the main current or the branch that should be checked and regulated by brattice and slide. The volume of the branch current should be just sufficient to enable the operations in the working place to be carried on in good air (about 4–5 cubic metres per man, on account of the loss by leakage).

Parallel Headings.

209. Another method of working headings that are not in connection with the rest of the pit consists in driving two parallel headings, about 12–15 yards apart, and connecting them by cross drives at intervals of 20–30 yards. As the work advances, and fresh cross drives are made, those in the rear are closed by packing with mining waste or by dams.

As a rule, this method of parallel headings will only be employed when the deposit can be reached from both, and the cost of driving them be recovered, wholly or in part, through the coal won. The air may be supplied either by the main current or by a branch therefrom. The modulus is calculated in the same manner as when brattices are used.

AIR TUBBING.

210. The cheapest and best method, however, of ventilating blind headings is by means of tubbing, *i.e.* pipe mains, usually arranged against the roof of the heading, and through which the fresh air is either delivered to the working face by blowing, or removed by suction. Wooden tubbing, of square section, such as was formerly used, is inefficacious, being difficult to keep air-tight, producing too much resistance, and being of insufficient dimensions.

On this account tubbings are now made of sheet-zinc pipe, or preferably of smooth galvanised iron, $\frac{1}{16}$ to $\frac{1}{12}$ of an inch thick, made up in the form of pipes by riveting and soldering the longitudinal joint, the separate lengths being connected together by riveted collars (Figs 145*a* and *b*), or, better still, by loose flanges and screws, as shown in Fig. 146.

The method of fixing the tubbing in position at the roof of the gallery is shown in Figs. 145*b*, 147, and 148. The collars are luted with clay, or preferably with a mixture of 1 part by weight of tallow and $1\frac{1}{2}$ part of resin. The joints of the flanged pipes are tightened by inserting rubber washers or rubber cord. For passing round curves, pipes bent to a circular arc are used, angle pipes causing excessive resistance.

The movement of the air in the tubbing may be either in the direction of the working place, or in the opposite direction; in the former case the tubbing acts as a blower, in the other as an exhaust (see Figs. 149 and 150, Plate XXX.).

In either event the movement of the air is caused by the general air pressure of the main current, or else by means of a special source of power, as will be seen later on. In both cases S represents the main heading through which the fresh air is introduced, *pp* are air dams traversed by the tubbing, and G is the blind heading ventilated by the latter.

VENTILATION BY TUBBINGS—BLOWING *v.* SUCTION.

211. (1) As a rule, it is better to blow the air through the tubbings than to exhaust through them. In the first place, more air is delivered by the former method; furthermore, all the air passing through the tubbing to the working face is pure and fresh, whereas that drawn off through an exhaust tubbing is warmer, moist, and often laden with powder, smoke, or firedamp, the consequence being that, for a given expenditure of motive power, a larger amount of pure air is delivered through a tubbing by blowing than by suction.

(2) The air delivered to the working place is pure, whilst, when the

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tubbing works as an exhaust, the air drawn through the heading may be laden with foul gases, especially firedamp when present.

(3) The working face is better ventilated when the air is blown through the tubbing, because in that case the air issues at high velocity from the narrow tubbing, and impinges on the face with considerable force, the result being to dilute and carry away any firedamp or powder gases present. With an exhaust tubbing this is never the case, it being impossible to place the end of the tubbing sufficiently close to the face; and, consequently, the air drawing slowly into the heading barely reaches the face, but turns back into the tubbing before arriving that far.

The sole defect of blowing is that the contaminated air returns to the haulage ways, where men are moving about with lamps. In fiery mines care must be taken to prevent any accumulation of any explosive mixture against the roof. Where, however, this is liable to occur, the lower part of the heading should be obstructed by curtains at intervals, in order to force the air current to stream along the roof and thus remove any dangerous gas present.

Under certain circumstances the two methods of working with air tubbings can be combined, as is shown in Figs. 151*a* and *b*.

Here, as will be apparent from the drawing, the main ventilating current enters from the cross drivage on the left hand, and is split into three currents in the drainage gallery, one of them being delivered through a tubbing *ab* into the blind heading on the right. Through an exhaust tubbing *cd*, which may be duplicated if too small, the split current is then discharged into the rise *fg*, which conveys it to the upper air level.

Two sets of tubbing—one blowing, the other exhausting—may also be used under other circumstances, *e.g.* when an advance has to be made into headings that are of high temperature or charged with poisonous fire gases. Both tubbings must then be provided with separate motive power, and so arranged that the exhaust tubbing is mounted above, and the blowing one ends somewhat in advance of the other.

These different kinds of tubbings are also employed in deepening shafts. Figs. 152 and 153 represent sketches of shaft deepening, a portion of solid rock being left behind for the purpose of ventilating by combined blowing and suction. As a rule, in deepening winding shafts, the rock is left solid for a certain distance below the winding compartment alone, the other portion of the shaft being deepened, and then widened out to the full a few yards lower down. In such cases it is best to introduce the air direct from the upper atmosphere through a blowing tubbing.

CALCULATING THE MODULUS OF AIR TUBBINGS.

212. Air tubbings offer some resistance to the passage of air, and have a modulus, like shafts and headings. It is absolutely necessary that this modulus should be ascertained, and borne in mind during ventilation. As before, the modulus $t = \frac{S^3}{PLK} = \frac{1S^3}{KPL}$, and the tubbing is assumed as being of circular cross section. According to Daubisson, the value K may be generally assumed as 0·0004, although smaller values, 0·0002 to 0·0003, are also given. $\frac{1}{K}$ is therefore = 2500.

If P and S be expressed as function of the diameter d of the tubbing, we have: $P = 3{\cdot}141d$ and $S = 0{\cdot}785d^2$, or $S^3 = 0{\cdot}484d^6$. In such event—

$$t = \frac{2500 \times 0{\cdot}484d^6}{3{\cdot}14d \times L} = \frac{2500 \times 0{\cdot}154d^5}{L} = \frac{385d^5}{L} \quad (A).$$

Since the pressure $h = \frac{Q^2}{t} = \frac{Q^2L}{385d^5}$ (B), then, h being known, we have

$$Q = \sqrt{\frac{h \times 385d^2}{L}} \quad (C).$$

Since the air that enters through the tubbing flows back through the heading, the modulus of the latter must also be ascertained.

Example.—Take the case of a blind heading 2 metres high and the same breadth, the sectional area being therefore 4 square metres; and let the diameter of the tubbing be 0·4 metre, the volume of air to be delivered per second 0 = 0·5 cubic metre, and the length of the tubbing 80 metres.

According to formula (A), the modulus of the tubbing is—

$$t = \frac{385d^5}{A} = \frac{385 \times 0{\cdot}01024}{80} = 0{\cdot}04928.$$

For the heading, the coefficient of friction of which, K, may be generally fixed as 0·0018, the modulus $t' = \frac{1 \times 64}{0{\cdot}0018 \times 8 \times 80} = 55{\cdot}55$.

The two moduli being known, the additive modulus T_a for the tubbing and heading combined will be: $T_a = \frac{t \times t'}{t + t'} = \frac{0{\cdot}04928 \times 55{\cdot}5}{55{\cdot}59928} = 0{\cdot}05$.

The pressure required for the propulsion of 0·5 cubic metre of air will be: $h = \frac{Q^2}{T_a} = \frac{0{\cdot}5^2}{0{\cdot}05} = 5$ millimetres water gauge.

Hence an air pressure of 5 millimetres water gauge will be required to deliver ½ cubic metre of air per second through a tubbing 0·4 metre diameter and 80 metres long, into and out of a heading of similar length and of 4 square metres sectional area. This pressure must either be

derived from the main air current supplying the air, or else furnished by a separate source of power provided for the purpose.

The question now arises, which source of power should be drawn upon. It has already been stated (§ 139) that the force required to propel the separate current (in this instance, 5 millimetres water gauge) must be added to the depression required by the main current, when it is undesirable to diminish the total volume of air supplied to the pit. Hence, in such an event, one must be in a position to correspondingly increase the power of the ventilating engine. When this is impracticable, the sole alternative is separate ventilation by the aid of a special motor.

In the Saarbruecken district the provision of special fans, driven by compressed air or hydraulic power, is invariably preferred for the ventilation of preliminary workings, even when the main ventilating engine is sufficiently powerful for this purpose, it being found inconvenient to erect the necessary appliances at the branching of the split current, to enable the main current to perform the work of the branch current, more particularly since the resistance increases as the blind heading advances, and therefore would entail a progressive increase in the power of the main ventilating engine.

It is of course also necessary to gradually increase the power of any supplementary motor that may be used for separate ventilation in such cases. However, this is not a difficult matter in the case of fans driven by compressed air or hydraulic power, as described in §§ 139 and 140. In order to now enable it to be ascertained whether any inconvenience is likely to arise in the propulsion of a branch current by the main current, the following example of such a case is given below (see Fig. 154).

Example.—213. Let us assume that a blind heading, originally 50 metres in length, is to be gradually increased to 600 metres. The breadth is 3·5 metres and the height $2\frac{1}{2}$ metres. The tension in the main current, from which the heading in question is to be ventilated, is 80 millimetres water gauge, and the volume of air passing through the pit is 60 cubic metres per second.

The blind heading is to receive 0·5 cubic metre of air per second, through a tubbing 0·5 metre in diameter, fitted with flanged joints.

For a length of 50 metres the modulus of the blind heading is—

$$t_1 = \frac{385d^5}{l} = \frac{385 \times 0{\cdot}5^5}{50} = 0{\cdot}25.$$

For a length of 600 metres the modulus of the tubbing is—

$$t_2 = \frac{385d^5}{600} = 0{\cdot}02.$$

The circumference of the blind heading being P = 12 metres, the superficial area S = 8·75, and the length L = 50 metres, the modulus will be—

$$T_1 = \frac{S^3}{KPL} = \frac{8 \cdot 75^3}{0 \cdot 0018 \times 12 \times 50} = 620 \cdot 3.$$

When the length is increased to 600 metres the modulus will be—

$$T_2 = \frac{8 \cdot 75^3}{0 \cdot 0018 \times 12 \times 600} = 51 \cdot 69.$$

The additive modulus T_{a1}, for the heading and tubbing together, will be, for a length of 50 metres—

$$T_{a1} = \frac{t_1 \times T_1}{t_1 + T_1} = \frac{0 \cdot 24 \times 620 \cdot 3}{0 \cdot 24 + 620 \cdot 3} = 0 \cdot 24.$$

And when the length is 600 metres—

$$T_{a2} = \frac{t_2 \times T_2}{t_2 + T_2} = \frac{0 \cdot 02 \times 51 \cdot 69}{51 \cdot 71} = 0 \cdot 02.$$

Now it is evident, in the first place, that the velocity v of the main ventilating current could be utilised to force a branch current into the tubbing, as is done in the case of air cowls.

The volume of air in the main current being 60 cubic metres per second, and the sectional area of the main gallery being $3 \cdot 5 \times 3 = 10 \cdot 5$ square metres, the air velocity will therefore be: $60 \div 10 \cdot 5 = 5 \cdot 72$ metres.

The pressure h_1 required to force 0·5 cubic metre of air per second through 58 metres of tubbing and heading would be: $h_1 = \frac{q^2}{T_a} = \frac{0 \cdot 5^2}{0 \cdot 24} =$ 1·04 millimetres, and through a space of 600 metres: $h_2 = \frac{q_2}{T_{a2}} = \frac{0 \cdot 5_2}{0 \cdot 02} =$ 12·5 millimetres water gauge.

The force N_1 and N_2 required to propel the tubbing current through 50 and 600 metres respectively will evidently be merely slight—

$$N_1 = \frac{qh_1}{75} = \frac{0 \cdot 5 \times 1 \cdot 04}{85} = 0 \cdot 007, \text{ and}$$

$$N_2 = \frac{qh_2}{75} = \frac{0 \cdot 5 \times 12 \cdot 5}{75} = 0 \cdot 083 \text{ horse-power.}$$

The main current, however, in consequence of its inherent velocity $v =$ 5·72, exerts on the surface of the tubbing facing the current a pressure—

$$h_3 = \frac{v^2 \times 1 \cdot 133}{2g} = 1 \cdot 8894, \text{ or, say, 2 millimetres.}$$

This pressure is more than sufficient to do the work required at the start.

The case is somewhat different, however, when the heading attains a length of 600 metres, the pressure then required to overcome the resistance being 12·5 millimetres water gauge; and this the velocity of the

main current is incapable of supplying. It will then be necessary to narrow the main heading by a dam at the mouth of the blind heading, and throttle the current until it attains a tension of $80 + 12{\cdot}5 - 2 = 90{\cdot}5$ millimetres, in order to convey the 0·5 cubic metre of air to the face.

If previously the propulsion of 60 cubic metres of air at a tension of 80 millimetres necessitated a force of $N_3 = \frac{60 \times 80}{75} = 64$ horse-power—or, assuming the combined efficiency of the engine and fan as 33·3 per cent., 192 horse-power—the power now required to propel the air through 600 metres of heading, and deliver 0·5 cubic metre to the blind heading, will be—

$$N_4 = \frac{60 \times 90{\cdot}5 \times 3}{75} = 217{\cdot}2 \text{ horse-power.}$$

From this example it will be easy to decide in which cases the ventilation of blind headings should be effected by means of a separate source of power, or from the main current.

When the length of the heading, or tubbing, is only 50 to 60 metres, the main current may be drawn upon almost invariably, owing to the smallness of the resistance to be overcome; but, on the other hand, when the length is considerable, and especially when there are a number of such headings in work at the same time, it will be preferable to ventilate each separately by a small fan and attached motor.

214. The case will not be very different when the tubbing is replaced by parallel headings or brattices; the most that can be done with the main current in this event is to employ it for lengths somewhat greater than the foregoing limits of 50 to 60 metres, the resistance in the headings being a little lower than with tubbing.

However, a separate calculation must be made in every case.

Should it be desired to utilise the main current for the ventilation of very long blind headings (in which event it will be necessary to restrict the area of the main air way), the dimensions of the orifice in the air door will have to be determined, in order to sufficiently dam up the main current. Still, taking the foregoing example as a guide, let us proceed to calculate the dimensions of the orifice a from the formula for the orifice in a thin partition. This will give us—

$$a = \frac{Q}{2{\cdot}63\sqrt{h}} = \frac{60}{2{\cdot}63\sqrt{10{\cdot}61}} = 7 \text{ square metres.}$$

In this case the damper slide could be replaced, without special difficulty, by a sliding door on rollers, for the purpose of properly adjusting the size of the orifice.

215. The appliances and cost of separate ventilation have alread

been dealt with in §§ 139–141. In the Saarbruecken district the use of tubbing is preferred to parallel headings, or brattices, owing to the smaller expense.

In that district the driving of parallel headings is a costly affair, on account of the high rock pressure, the necessary timbering and repairs to the headings being expensive. Furthermore, under these conditions the vertical brattices are easily forced out of shape, and rendered leaky, despite constant supervision and repair.

The matter would be very different in thick seams and in cross drivages through firm rock, because in the former case the recovered coal would pay for the outlay involved, and in the other the brattices are less liable to become leaky; besides, a yard run of brickwork brattice is hardly any dearer than the same length of 20-inch galvanised iron tubbing. True, the old tubbings are still worth a considerable sum, and can be used over again, which cannot be said of the brattices. The latter, too, are always the cause of a constantly increasing waste of air.

The small fans for separate ventilation are generally 550–600 millimetres in diameter (less frequently 700 millimetres), and run at a speed of 400–700 revolutions per minute (rarely as high as 1000). They are driven by belting, the increase of speed being 1 : 4. The motors have a piston diameter of 50–60 millimetres, and are worked by compressed air (4–5 atmospheres) or hydraulic power (14–15 atmospheres), or else the motive power is supplied by a Pelton wheel 12 inches in diameter.

The following amounts of air are furnished by a Ser fan, 2 feet in diameter, and fitted with a double intake:—

Speed of Fan. Revolutions per minute.	Volume of Air delivered per minute through a Tubbing 262 millimetres (11 inches) in diameter, and 100 metres in length.
	Cubic Metres.
100	3·02
400	7·93
600	13·93
800	18·68
1000	23·39
1200	28·27
	Through a 350-millimetre (14 inches) Tubbing.
200	16·15
400	34·26
600	52·32
800	70·67
1000	—
1200	—

Speed of Fan. Revolutions per minute.	Volume of Air delivered per minute through a 500-millimetre (20 inches) Tubbing.
200	25·76
400	52·80
600	79·65
750	100·00
800	—

In the case of collar joints, the loss of air from the tubbings is—

Lengths of 100–200 metres	12 per cent.
„ 100–300 „	20 „
„ 100–400 „	26 „
„ 100–500 „	30 „

With good flange joints the loss of air is barely 8–10 per cent. for 600 metres.

The Supervision of Ventilation.

216. From what has gone before, it will be evident that the following circumstances contribute to the replenishing and purification of pit air:—

(1) The provision of a continuous current of air superior, in amount and motive power, to the momentary requirements of the pit.

(2) The utilisation of this current to the best advantage, and its distribution in a manner fulfilling the necessities of all parts of the workings.

(3) Incessant supervision of the ventilation, both as a whole and in all its details; since it by no means follows that, when a pit is well ventilated at a given moment, this ventilation will permanently remain in that condition.

The temperament is continually altering in consequence of the progressive increase in the workings. The condition of the pit may also be changed by accidental circumstances, such as the removal of air doors and curtains and the re-erection of same, the removal and renewal of air dams, obstruction due to the accumulation of filled or empty trucks in the haulage ways, etc. The draught may also be affected by the ascent and descent of the cages in the shaft; and finally, in fiery pits, the fluctuations in the volume of firedamp escaping from the coal have to be reckoned with.

When one remains for several hours in a pit one gradually grows accustomed to the atmospheric conditions, and less able to detect any changes therein, some other stimulant than natural sensation being required. Valuable indications will be afforded by constant determinations of the velocity and fluctuations of the air current, provided the same can be readily and conveniently made with sufficient precision.

For velocity determinations the anemometer is the sole means of obtaining accuracy (see §§ 75–82).

If a Krell anemometer, such as is described in § 81, be installed at a given position in the mine, the momentary fluctuations in the velocity and volume of the current can be detected at once.

Very slight differences in pressure, in headings and workings, which enable one to detect the influence of curves and sudden modifications in sectional area on the air pressure, can be revealed by the newer aneroid barometers. These are so sensitive that they will even record the difference in pressure occurring when the instrument is removed from a table and placed on the floor.

The Guibal Air Controller.

217. Guibal introduced another instrument, which he called an air controller, and which directly indicates the square of the volume of air passing by.

When a cylindrical vessel G (Fig. 155, Plate XXX.) is filled with water up to the line *nn*, and a rotary movement is imparted to the vessel, the surface of the water, instead of remaining horizontal, sinks at the centre and rises at the sides, thus forming a concavity representing a paraboloid of rotation.

In this case $y^2 = 2px$, and x therefore corresponds to y^2.

If, when the water is at rest, there be inserted at the centre a glass syphon, connected with an external vertical glass tube open at the top, then the rotation of the vessel and the resulting depression of the central portion of the water level will cause a corresponding depression of the water level in the outer tube.

The depression of the water level will be $x = \frac{w^2 r}{2g}$, when w expresses the angular velocity and r the radius of the vessel. Hence x is proportional to the square of the angular velocity, or the square of the volume of air in the current by means of which the vessel is set in rotation through the medium of the vanes with which it is fitted.

A more detailed description of this instrument can be passed over here, since it is somewhat complicated and troublesome to fit up in an upcast shaft, so that it has not yet been employed in practice.

Recording Pressure Gauge.

218. The recording pressure gauge shown in Fig. 156, Plate XXX., is known in Belgium as a "mouchard" (detective). It consists of a

vessel G, enclosed on all sides, and partly filled with water in which floats a bell g. The air space above the water level is put in connection with the culvert conveying the pit air, by means of an open tube r, so that the pressure of the pit air is transmitted to the water in G. The bell g, which is open at the bottom, fits closely into a similarly open cylinder c, and communicates with the outer air through the tube r'. According as the air pressure in the space s rises and falls the water level undergoes modification, and the bell g is raised or lowered, its motion being recorded on paper supported on a drum T by a pencil z attached to a rod d moved by the bell. The drum is actuated by clock-work, and makes a complete revolution every twenty-four hours, and, by the aid of the squares into which the paper is divided, furnishes an accurate record of the pressure obtaining in the pit at any hour or minute of the day.

Air Register and Ventilating Plans.

219. It has been already stated that in all fiery pits barometric observations have to be taken at regular intervals and entered in a register. This work must be performed daily, the readings being taken at fixed positions in different parts of the workings.

Furthermore, in all fiery and extensive pits, especially where a number of seams are being worked simultaneously, plans must be drawn and kept up to date, showing an accurate picture of the course taken by the various portions of the ventilating current and branches into, through, and out from the workings, giving the velocity and volume, and indicating the situation of each measuring station, air door, dam, brattice, air crossing, lamp room, explosives storeroom, etc. in the mine.

Arranging an Upcast Air Shaft for use as a Winding Shaft.

220. When it is desired to utilise an upcast air shaft for winding as well, each of the winding compartments may be enclosed at the mouth by an air-tight wooden shed, 13–16 feet high, and fitted with covers as shown in Fig. 157a, each cover being provided with an orifice for the passage of the winding rope. In order to prevent damage to the cover by the swing of the rope, a movable iron sheath (Fig. 157b) surrounding the rope and following its lateral movements is inserted in the cover. When the ascending cage arrives at bank it carries the cover up with it, and returns the latter into position. During the time the cover is raised the tight-fitting bottom of the cage prevents the outer air slipping by and entering the culvert G leading to the fan.

In other cases the entire pit mouth is enclosed in an air-tight chamber or air-lock, the winding rope passing through small apertures in the roof, in order to reduce the indraught to a minimum.

The air-lock is closed on the outside by two tight-fitting air doors. The first described method (recommended by Briart) is preferable, owing to the ease with which the air-lock doors can be injured, and the consequent expense of repairs and waste by leakage.[1]

Speaking generally, it is inadvisable to make use of upcast shafts for winding; and, when this is done, it is essential that the winding and ventilating compartments should be isolated in a perfectly air-tight manner; since, in the event of a pit fire or firedamp explosion, the air in the upcast will be so charged with poisonous carbon monoxide as to be imminently dangerous to the life of anyone exposed thereto for even a few minutes. In such event, it will also be well-nigh impossible to provide means in the return air way of keeping the poisonous gases from gaining access to the loading place at the pit eye and the haulage ways, etc. connected with the same.

[1] *Translator's Note.*—At the Minister Stein Pit, near Dortmund, the air-lock at the mouth of the combined upcast and winding shaft is of very solid construction, the pit mouth being enclosed by a brick building, and the doors at the two ends of the actual air-lock are hung—or rather swing—on central pivots, so as to minimise the trouble of opening them, and to prevent slamming. This arrangement should remove the objection raised by the author.

THE END.

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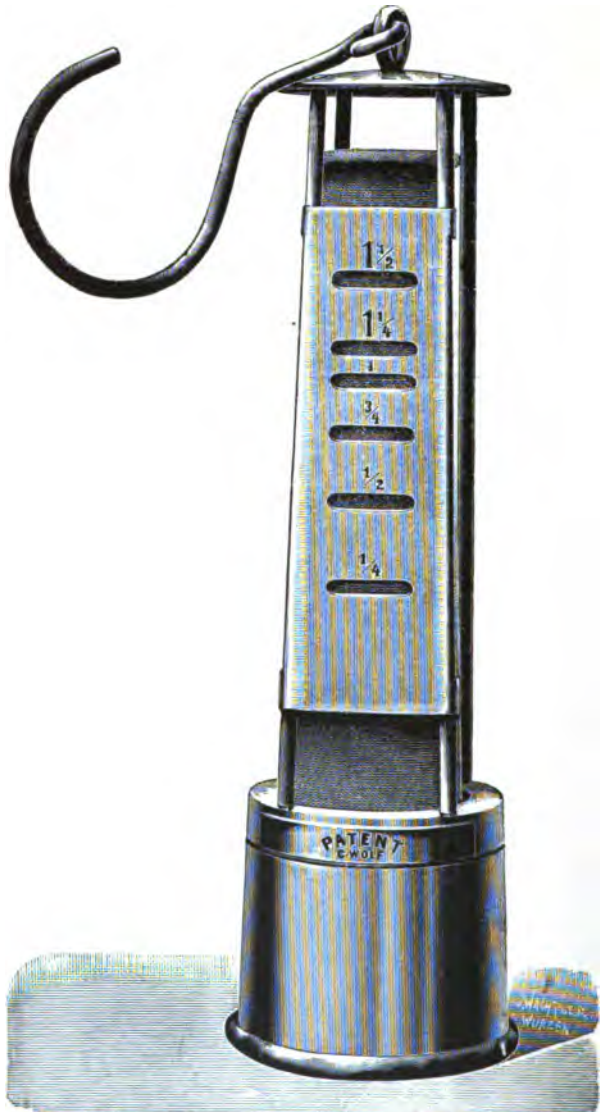

Fig. 2.

The Pieler Lamp.

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with

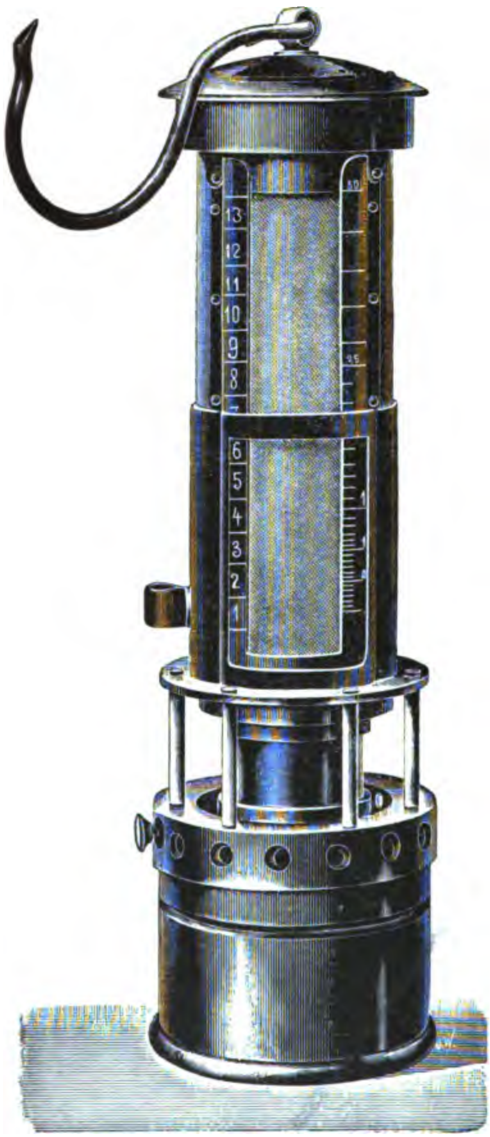

Fig. 5.

Chesneau
Firedamp Testing Lamp.

Fig. 6.

Wolf's Patent Miner

with Bottom D

Safety Lamp

ught.

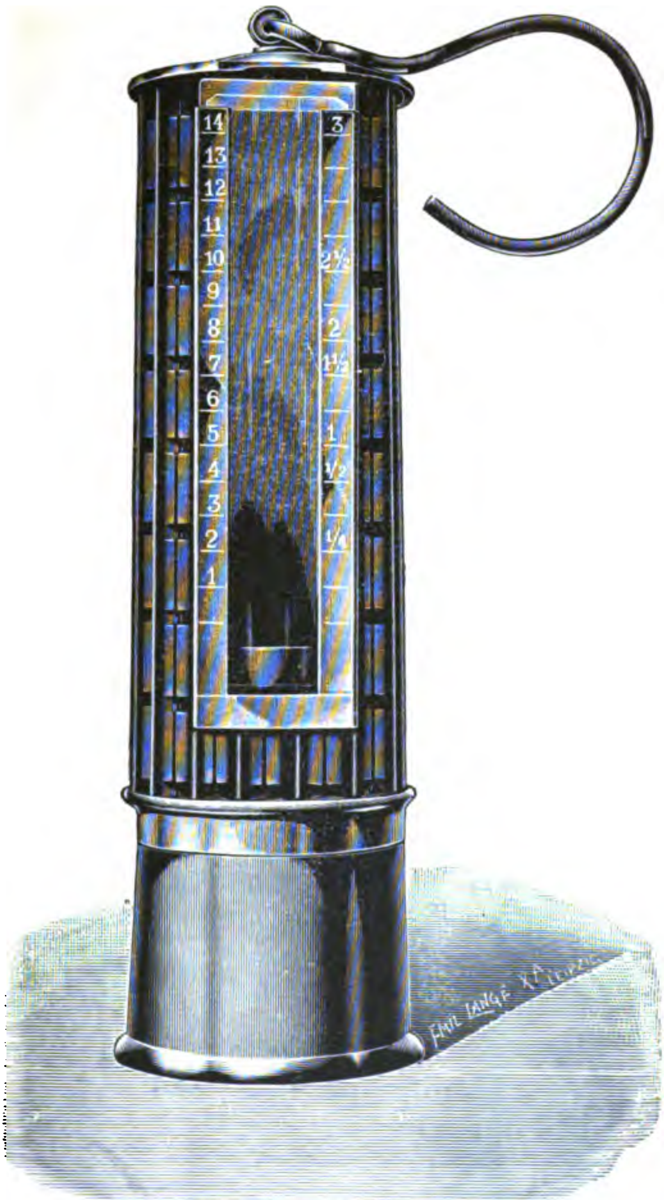

Fig. 6a.

Wolf's Patent Miners' Safety Lamp

with Bottom Draught.

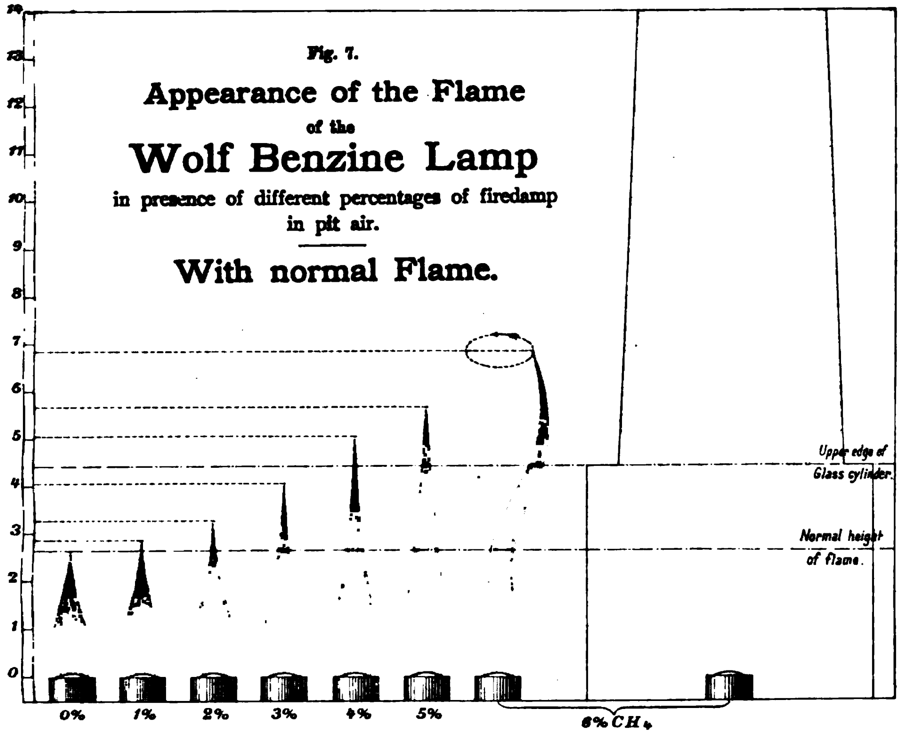

Fig. 7.

Appearance of the Flame of the Wolf Benzine Lamp in presence of different percentages of firedamp in pit air.

With normal Flame.

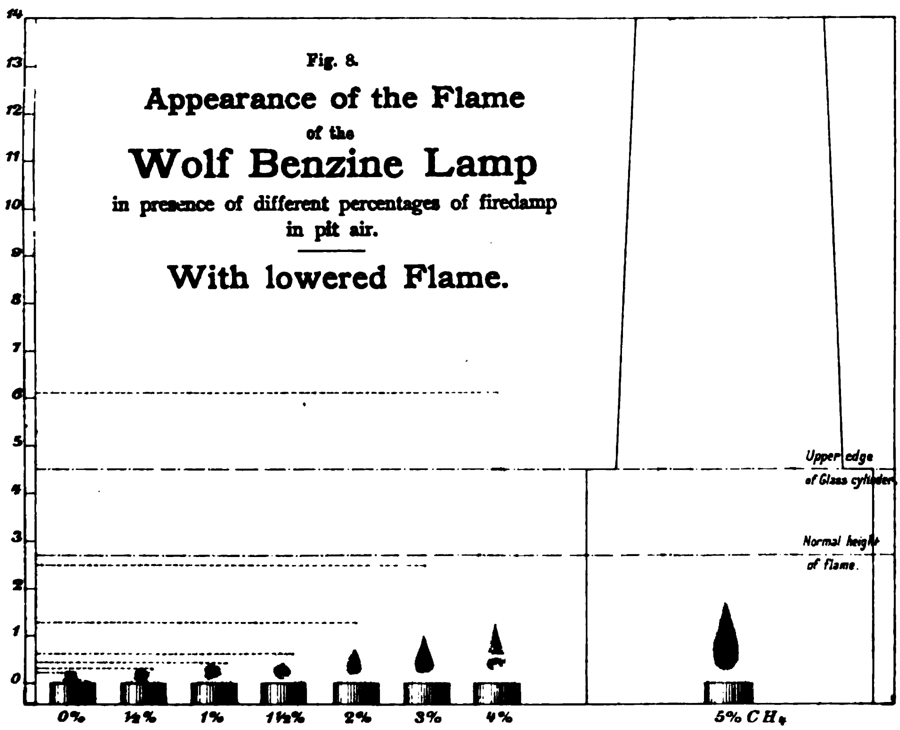

Fig. 8.

Appearance of the Flame of the Wolf Benzine Lamp in presence of different percentages of firedamp in pit air.

With lowered Flame.

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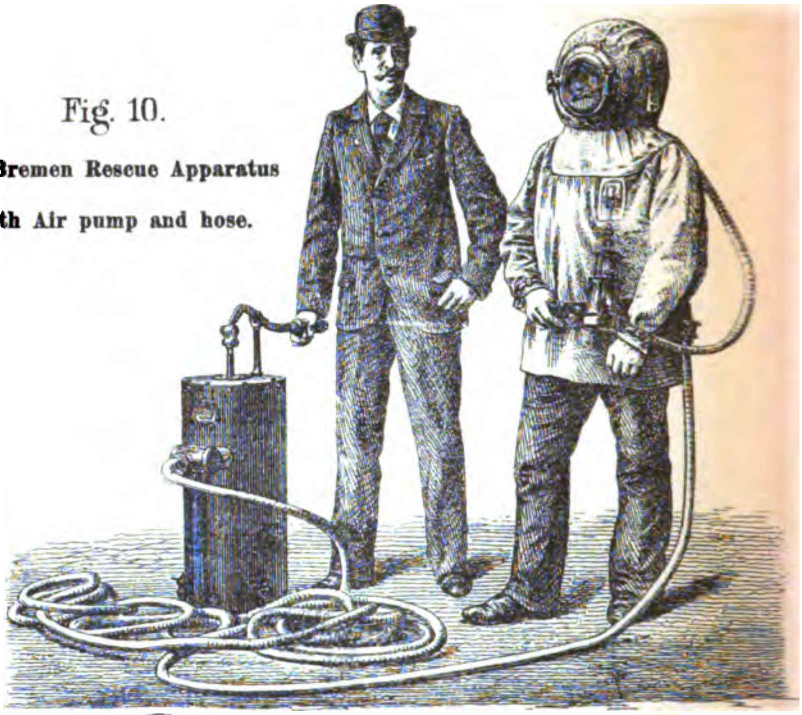


Fig. 10.

The Bremen Rescue Apparatus with Air pump and hose.

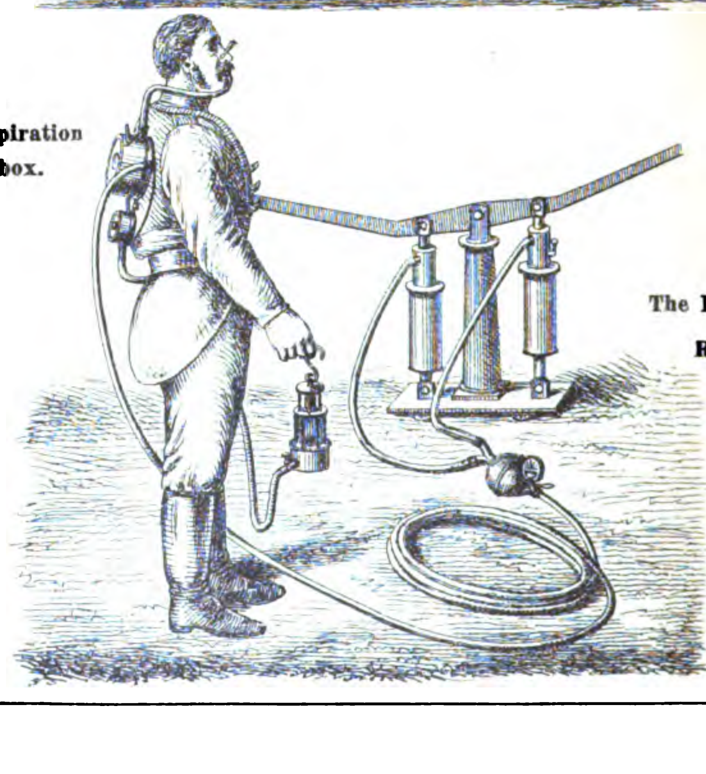


Fig 12.

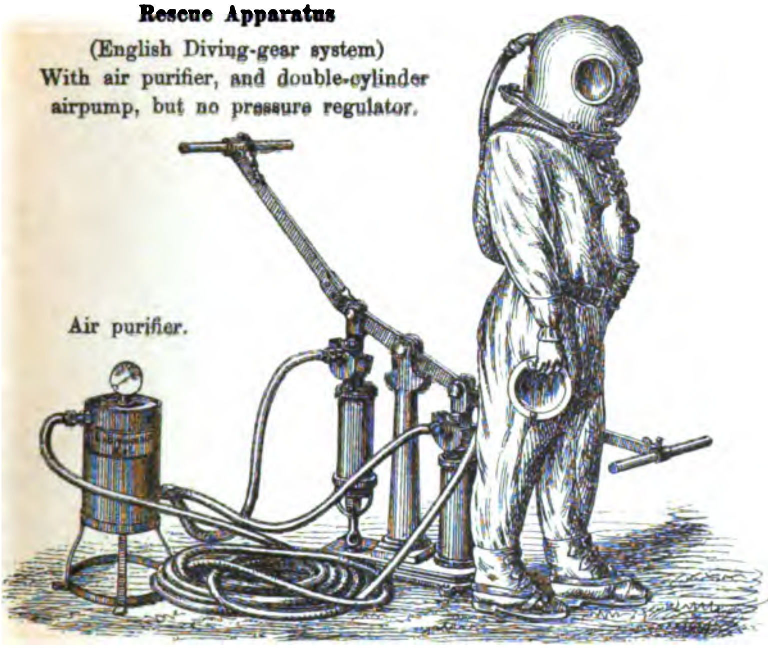
The Bremen Low-p
Rescue Appara

Plate IV.

Fig. 11.

Rescue Apparatus

(English Diving-gear system)
With air purifier, and double-cylinder airpump, but no pressure regulator.



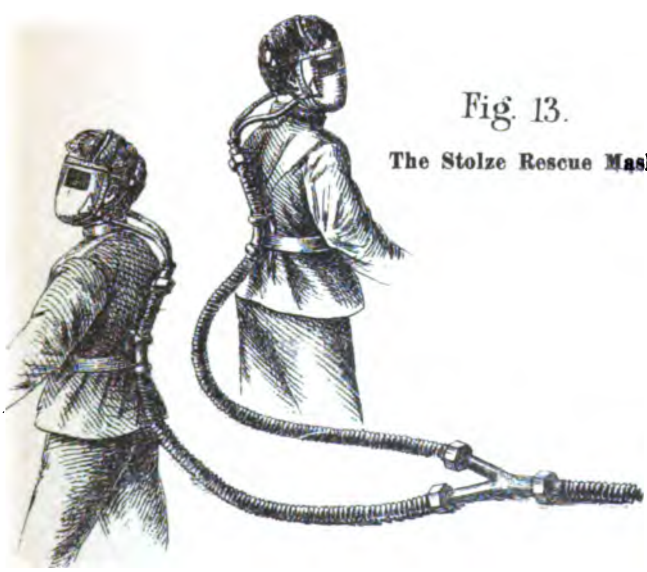


Fig. 13.

The Stolze Rescue Mask.

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Fig. 14.

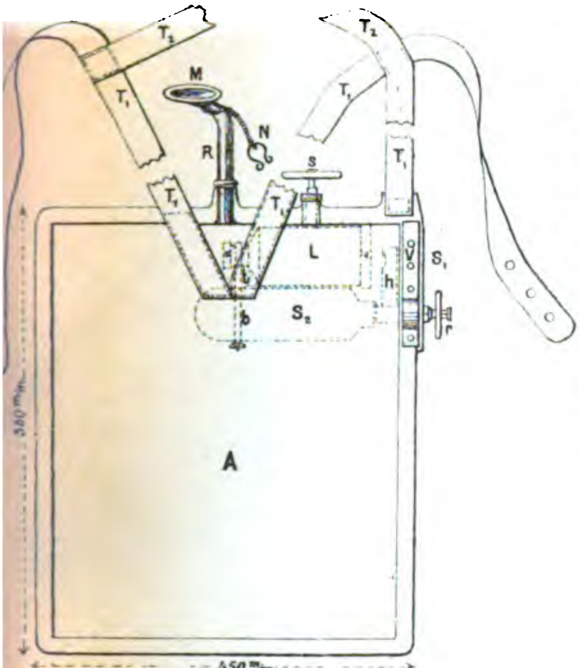
The Müller Smoke Helmet.

Fig. 16.

Fig. 17.

Fig. 15.

Walcher-Gaertner Respiration bag with Oxygen bottle S_2 and Soda flask L.



A — Respiration bag.
M — Mouthpiece.
R — Respiration tube.
S_1 — Slit in bag.
$T_{1,2}$ — Suspenders (removable).
N — Nose clamp.
L — Alkali holder with flask.
S_2 — Oxygen bottle.
V — Locking bars.
b — Sling band.
h — Branch discharge tube on neck of oxygen bottle.
r — Valve wheel on oxygen bottle.
s — Worm wheel for smashing the alkali flask.

Fig. 18.

Miner with improved Walcher-Gaertner Rescue Apparatus, and with the Schweitzer Rescue Plank.

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The Ne

Respirati

(Fig. 19, 19a

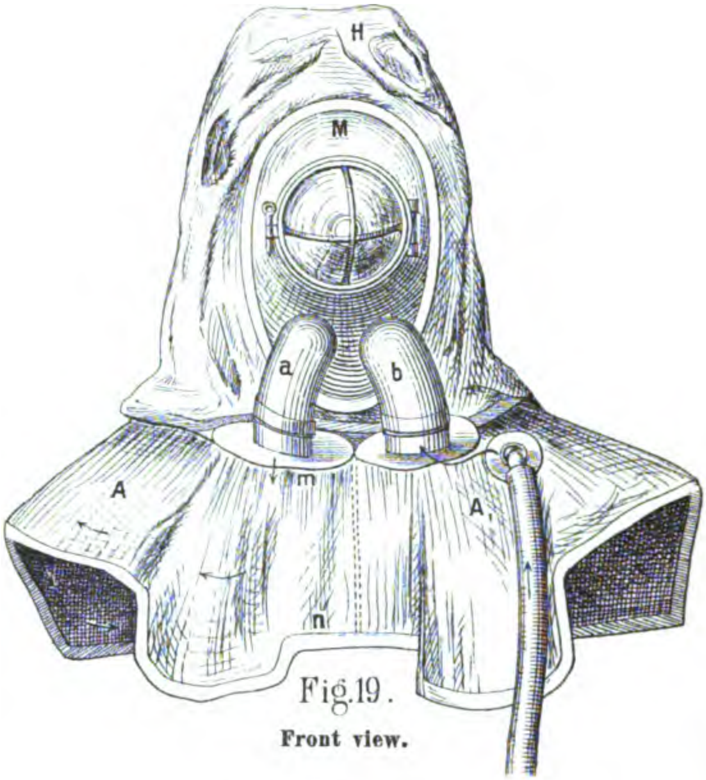


Fig.19.

Front view.

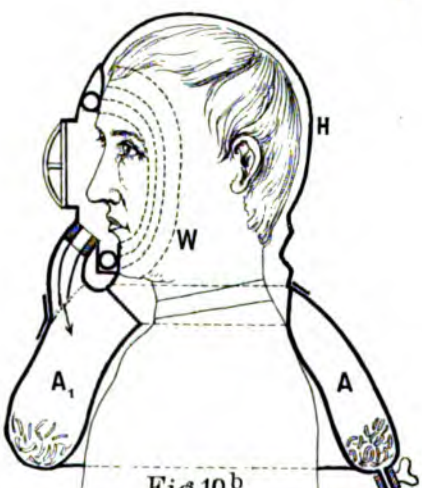


Fig.19b.

Vertical section.

rt Oxygen

Apparatus.

b, 19c und 20.)

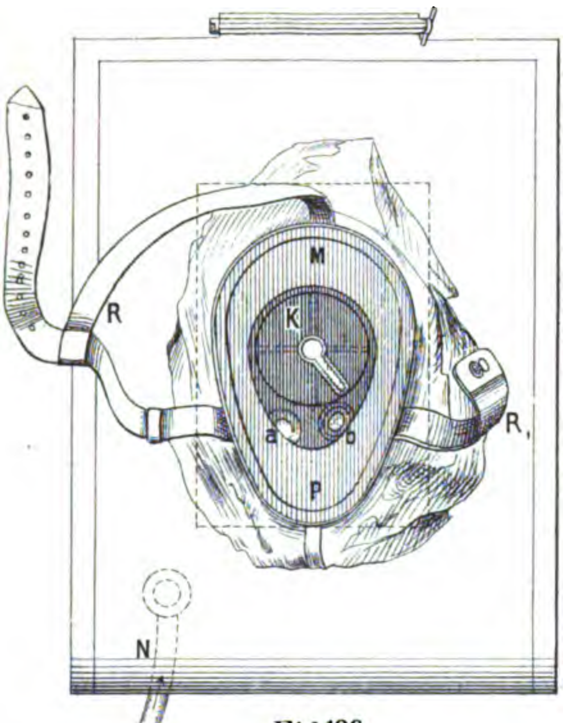
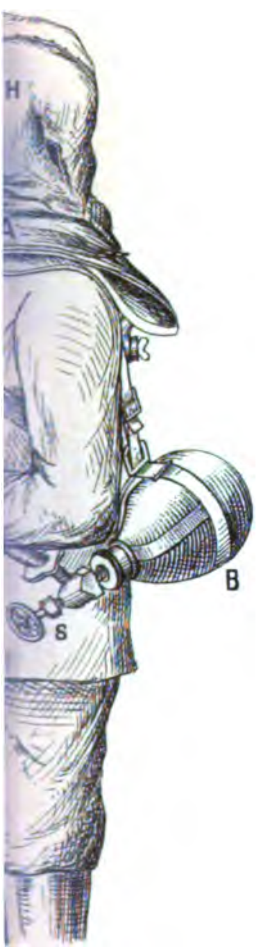


Fig. 19c.



ig. 19a.

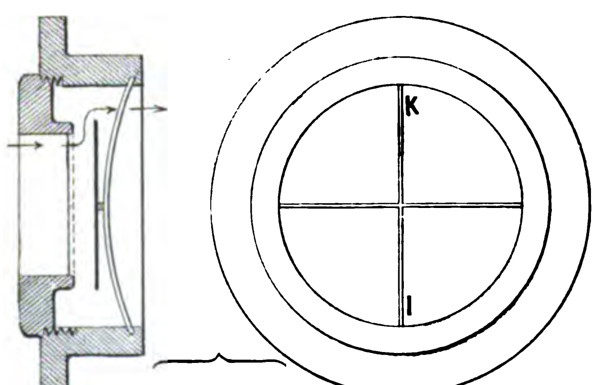


Fig. 20.

Respiration Valve.

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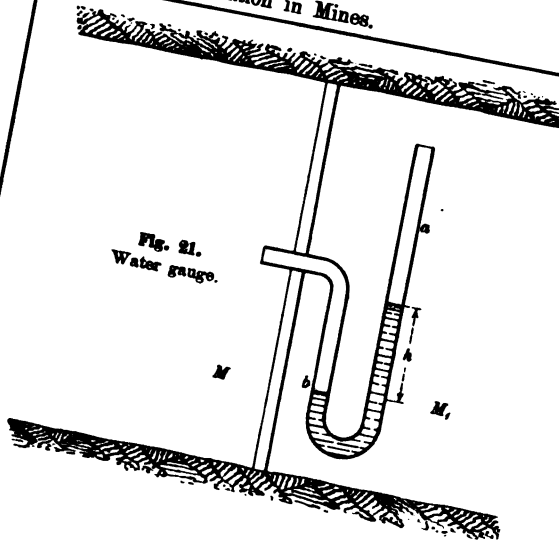
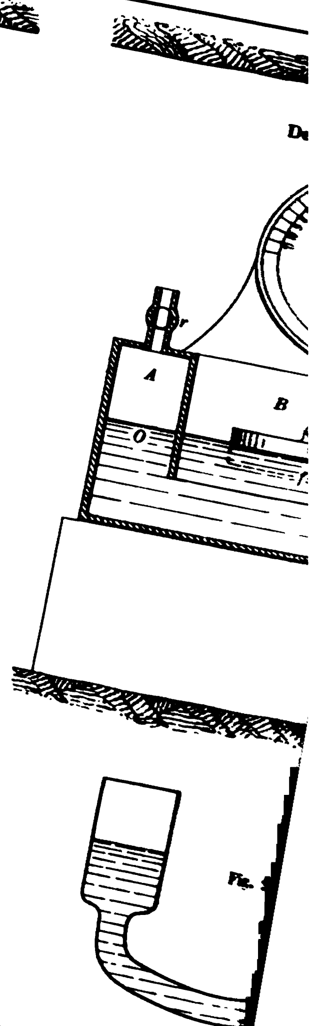


Fig. 21.
Water gauge.



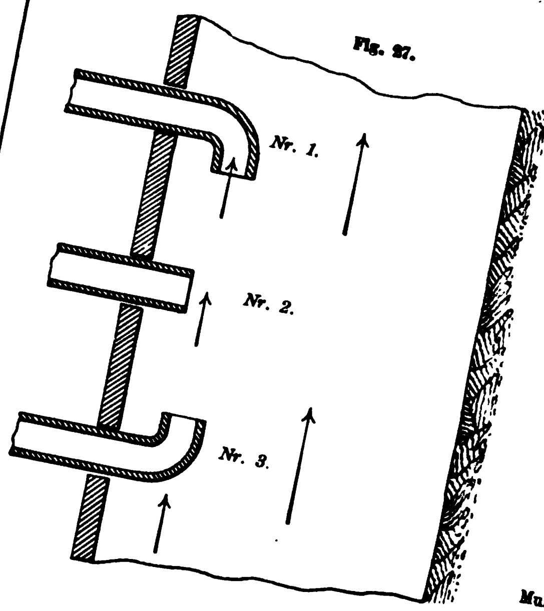
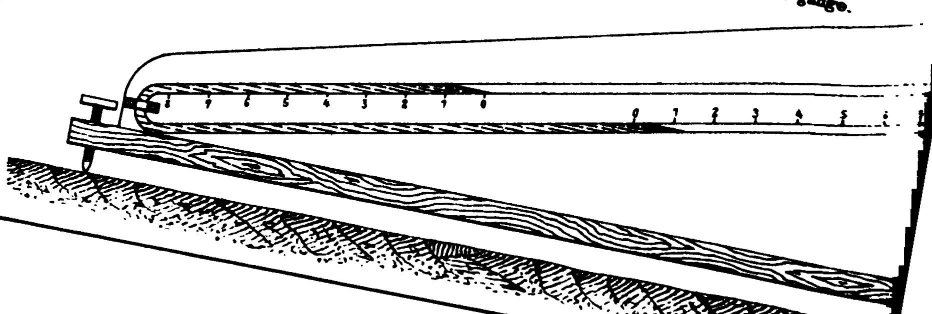
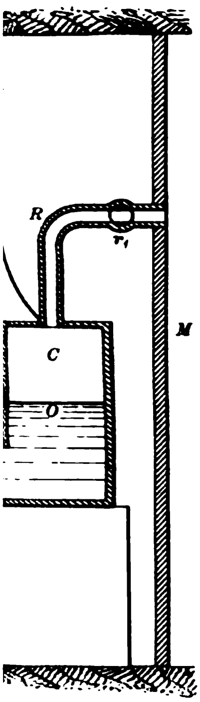
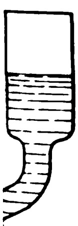


Fig. 27.

Fig. 28.
Multiplication pressure gauge.







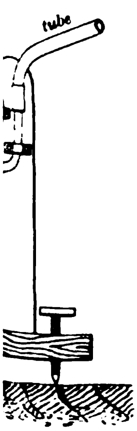


Fig. 25.
The Maess Vacuum meter with floating scale.

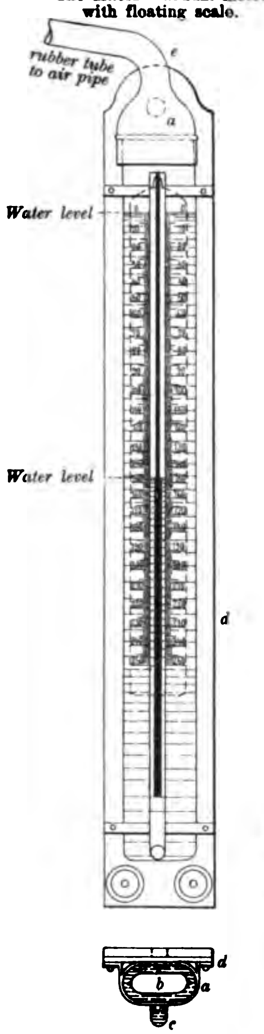


Fig. 24.
Guibal pressure gauge.

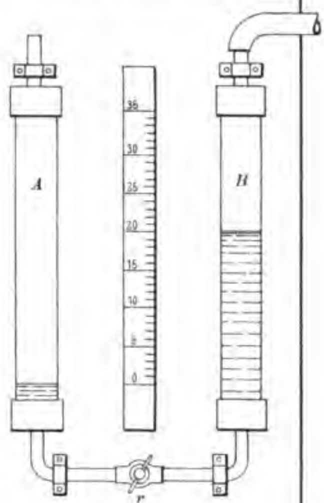


Fig. 35.
Whim for testing Anemometer fan.

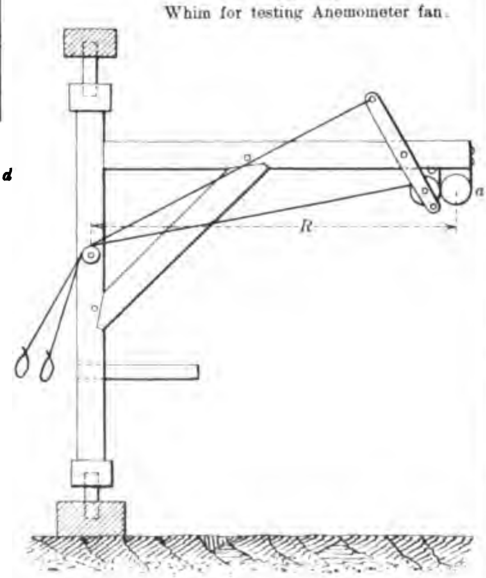


Fig. 39.

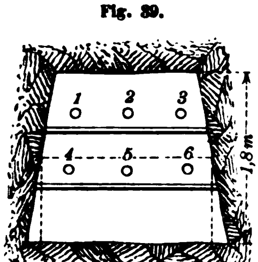


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Fig. 39.
Stand for mounting Anemometer.

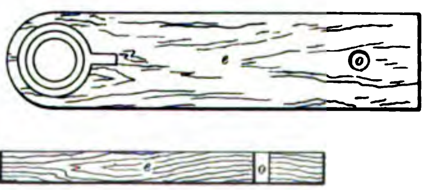


Fig. 40.

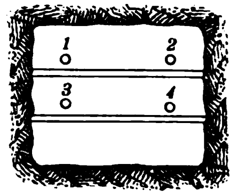


Fig. 41.

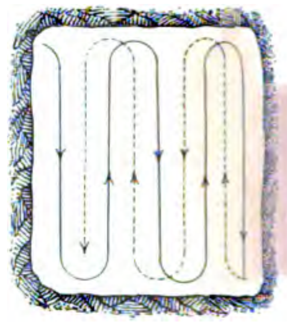


Fig. 42.

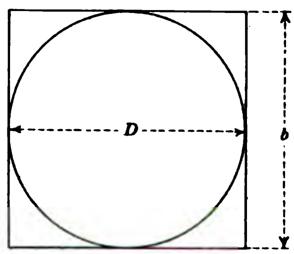
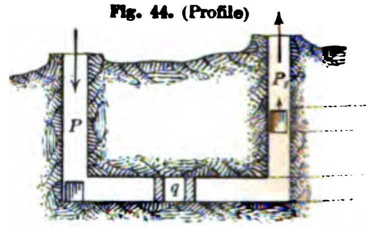


Fig. 44. (Profile)



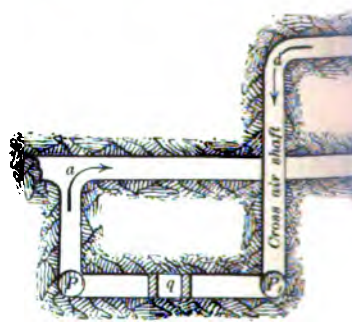


Fig. 48.

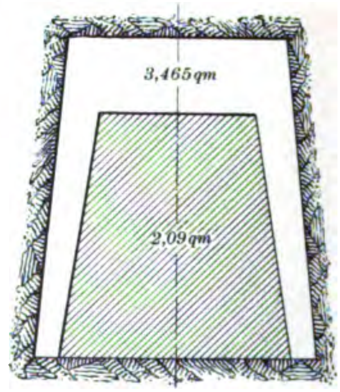


Fig. 49.

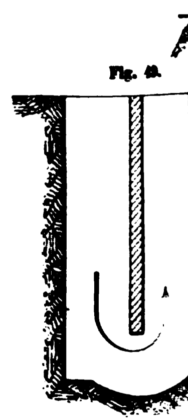


Plate VIII.

Fig. 46.

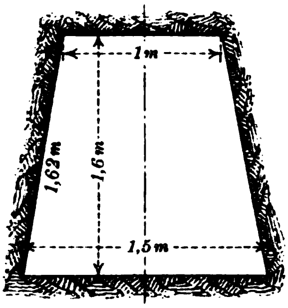


Fig. 48.

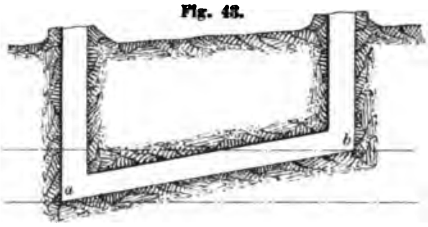
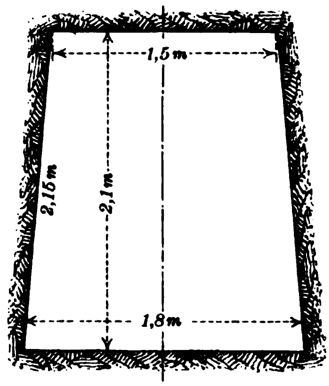


Fig. 47.



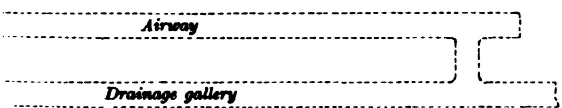


Fig. 45. (Ground plan).

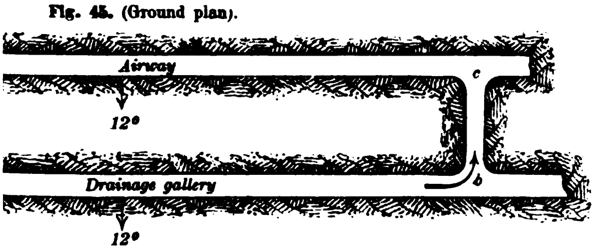


Fig. 52.

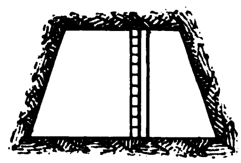


Fig. 50.

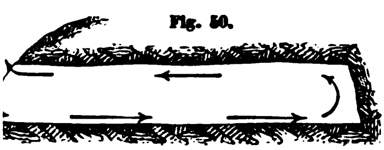


Fig. 51.

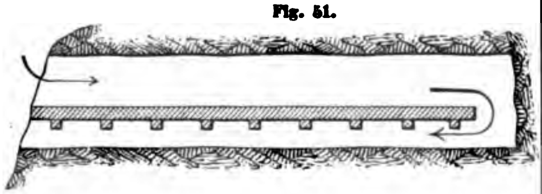


Fig. 53.

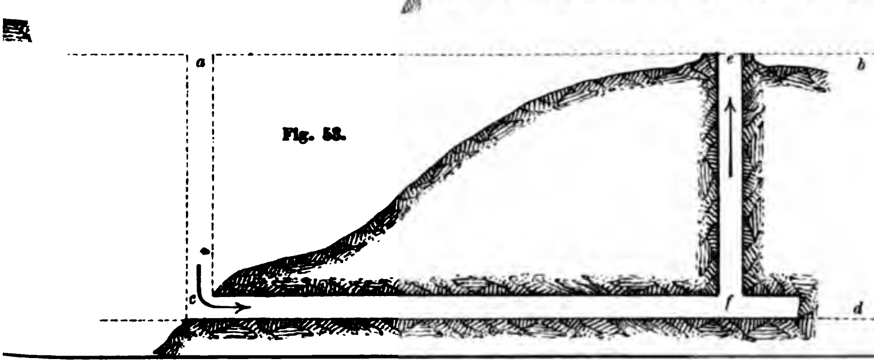
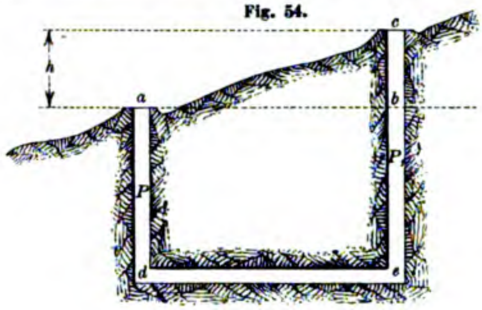


Fig. 54.



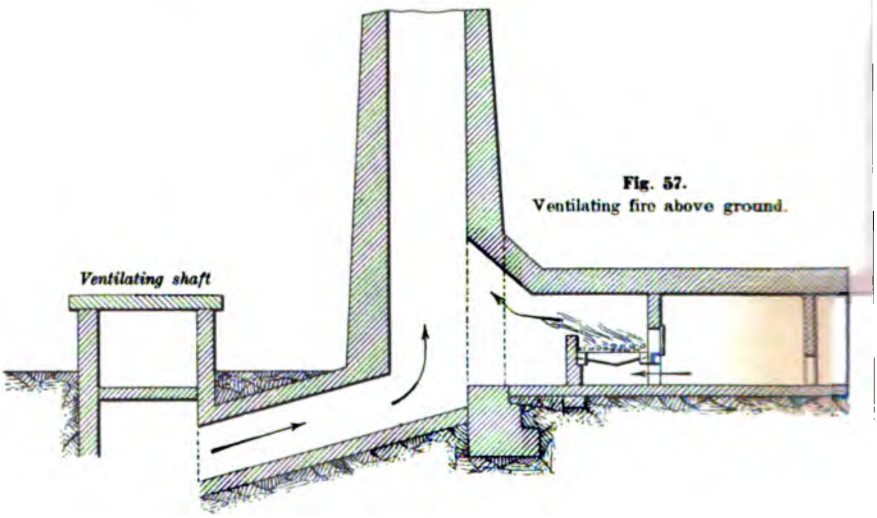
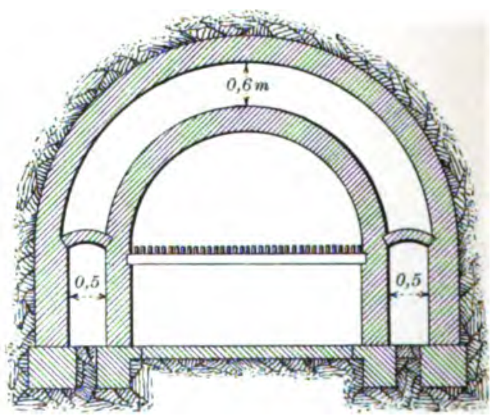


Fig. 57.
Ventilating fire above ground.

Fig. 59 a.



…. 55.

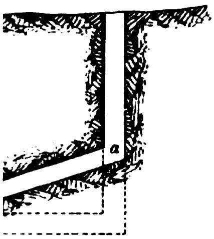
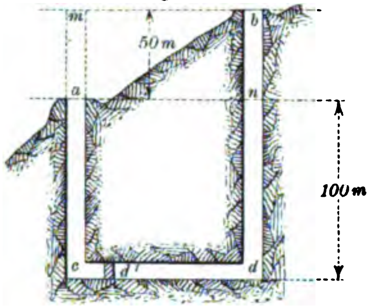


Fig. 56.



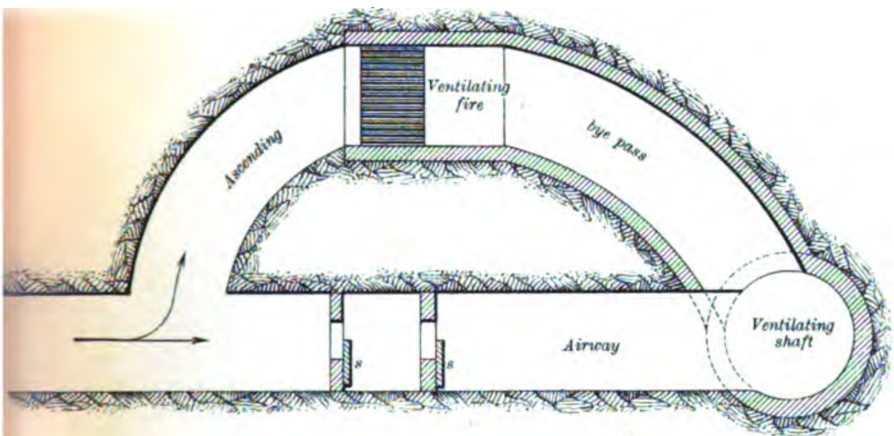


Fig. 59 b.

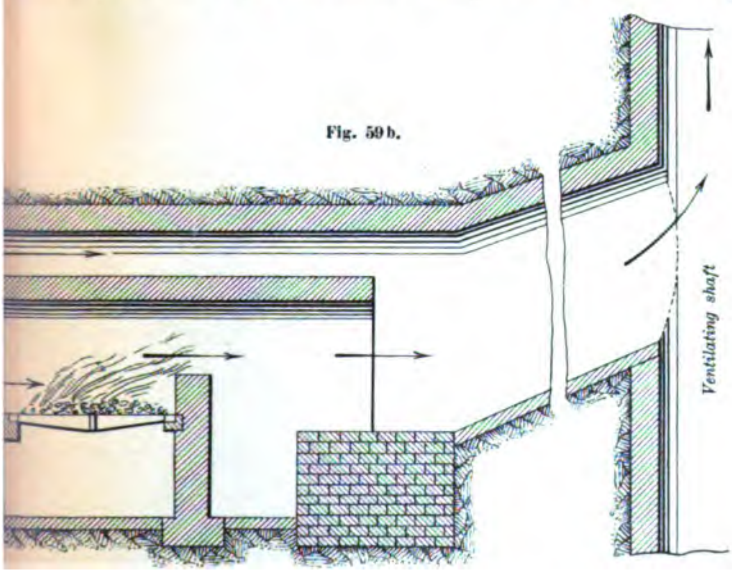


Fig. 60 a.

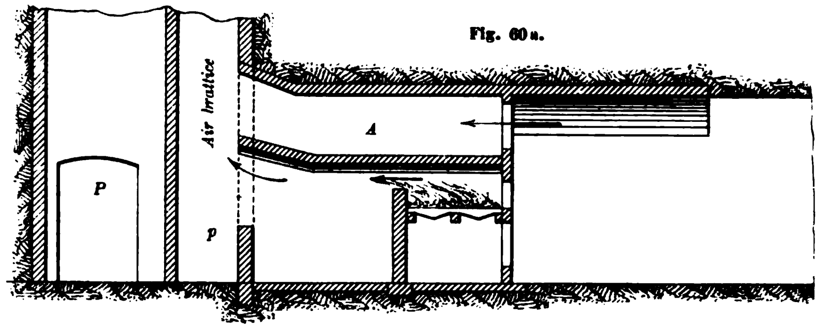


Fig. 60 b.

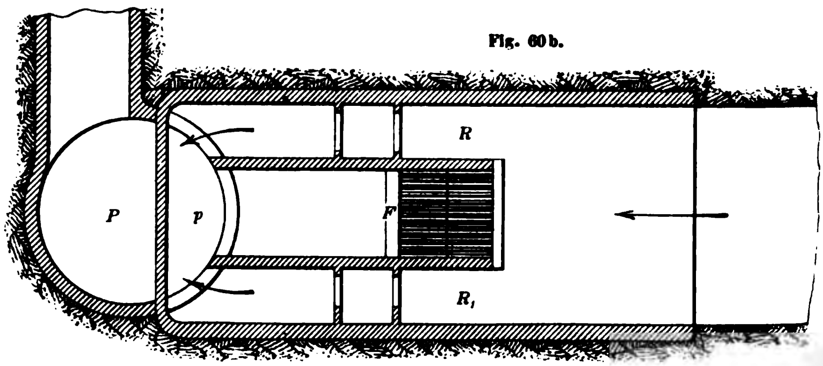
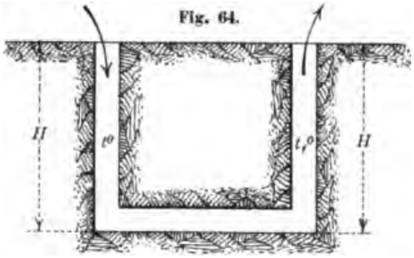


Fig. 64.



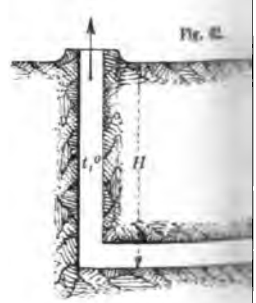
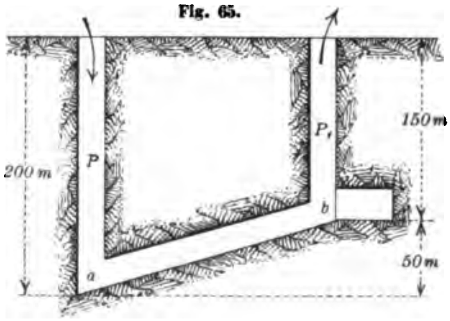
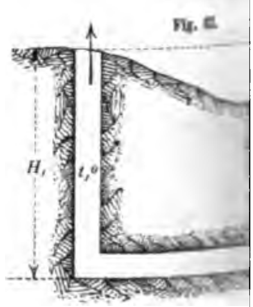


Fig. 65.





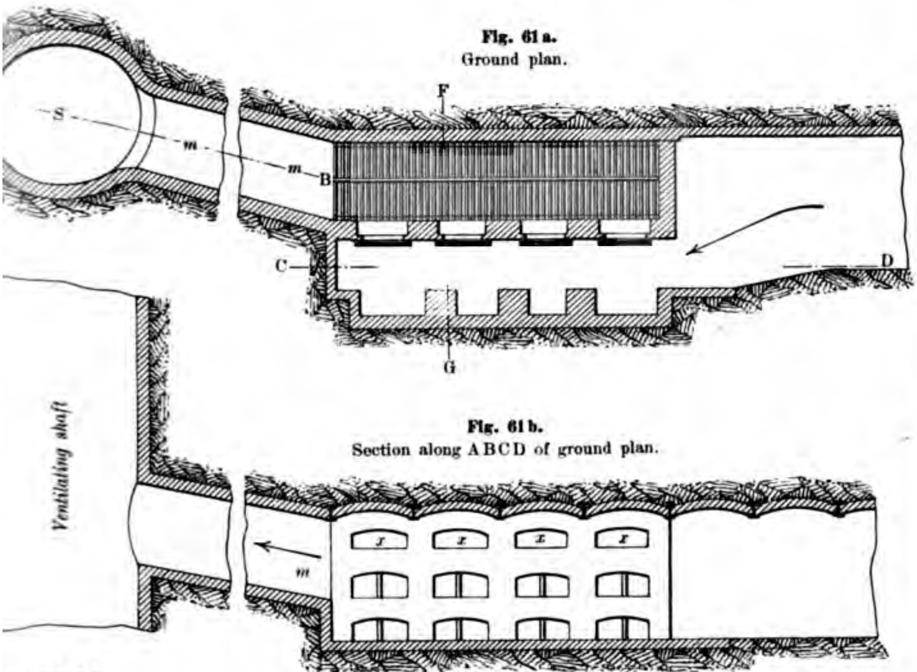


Fig. 61 a.
Ground plan.

Fig. 61 b.
Section along A B C D of ground plan.

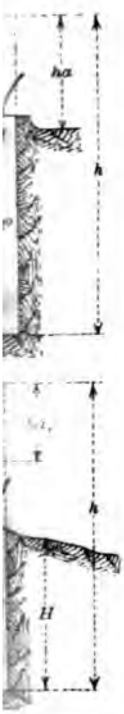


Fig. 61 c.
Section along F G.

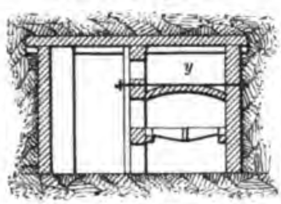


Fig. 66.

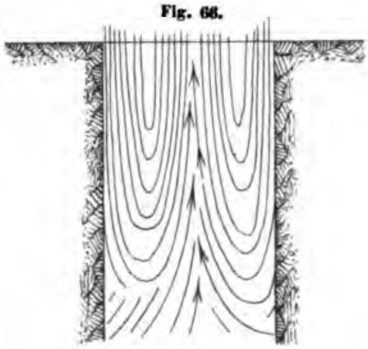
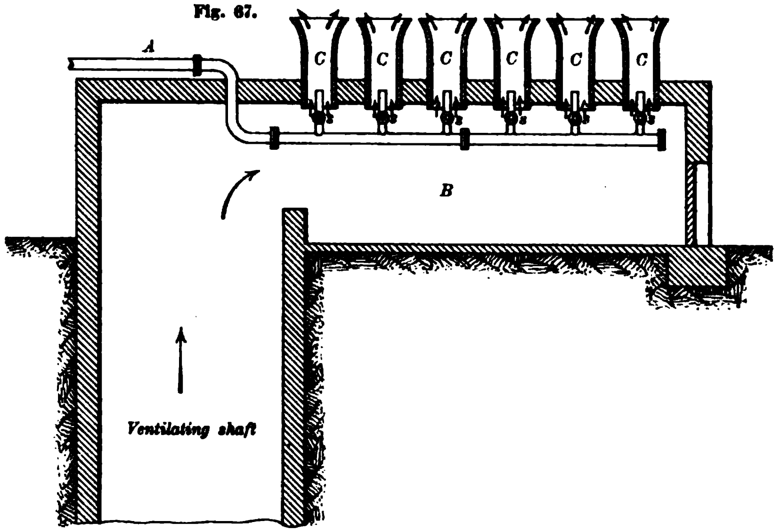


Fig. 67.



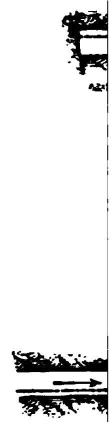
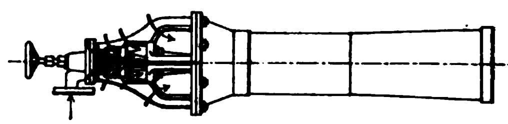


Fig. 70.



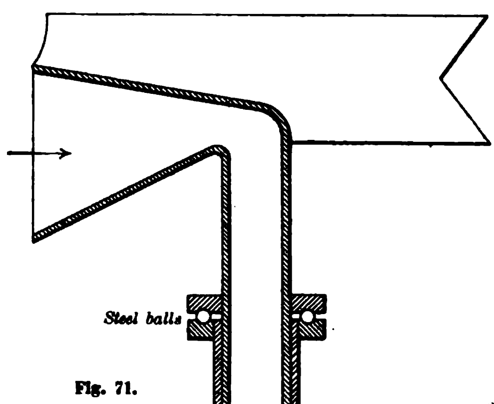
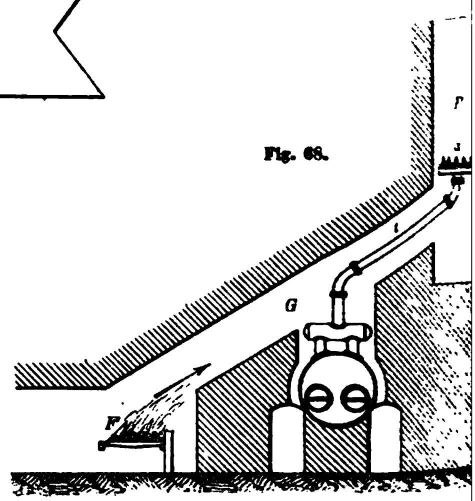


Fig. 71.

Fig. 68.



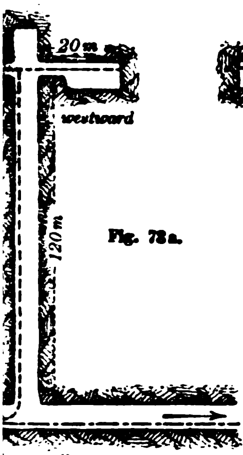


Fig. 78 a.

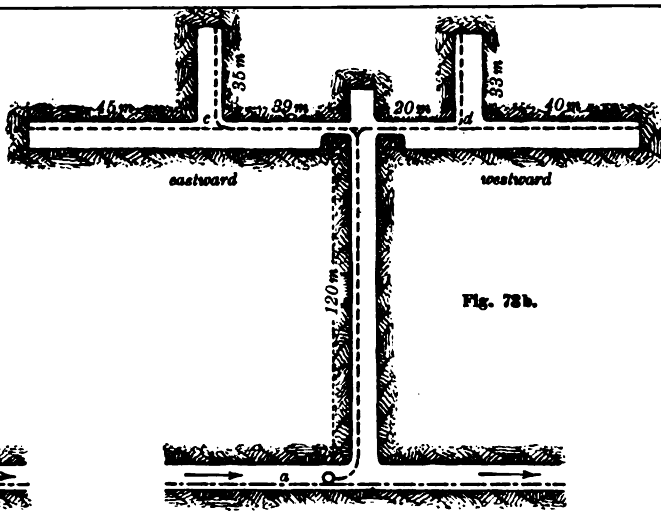
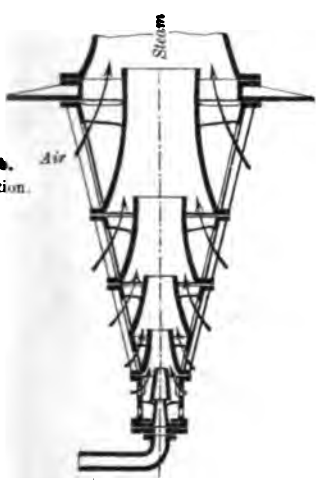


Fig. 78 b.



...g. 69 b.
... Section.

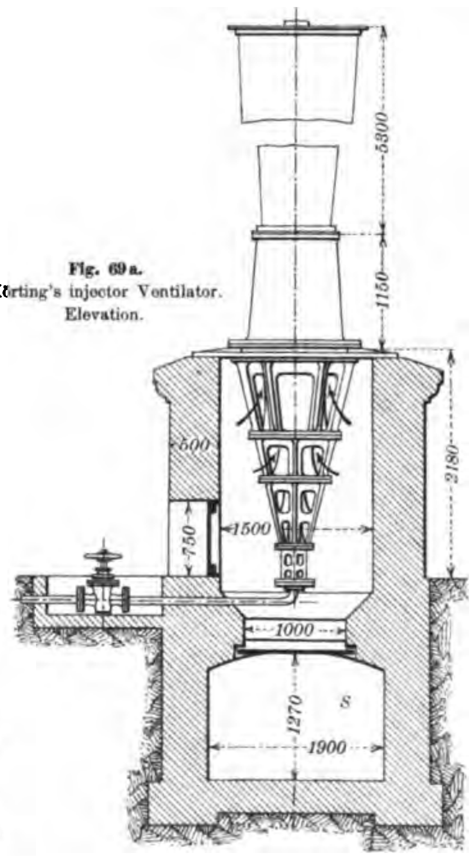


Fig. 69 a.
Körting's injector Ventilator.
Elevation.

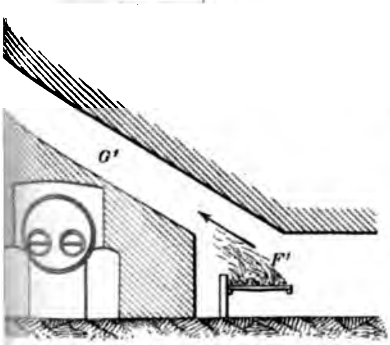


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Fig. 72.

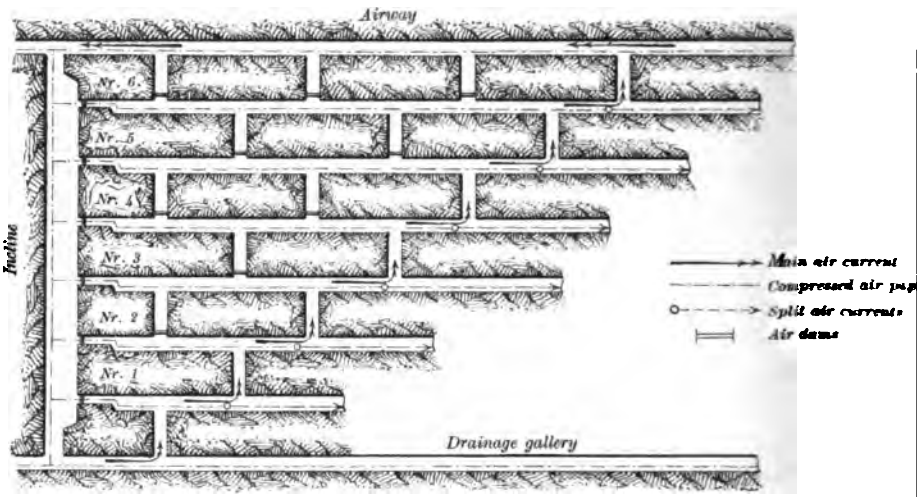


Fig. 75.

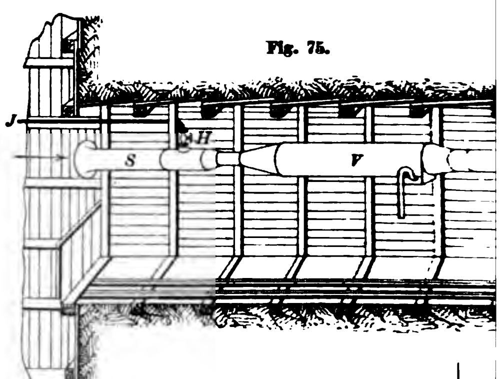


Fig. 76.

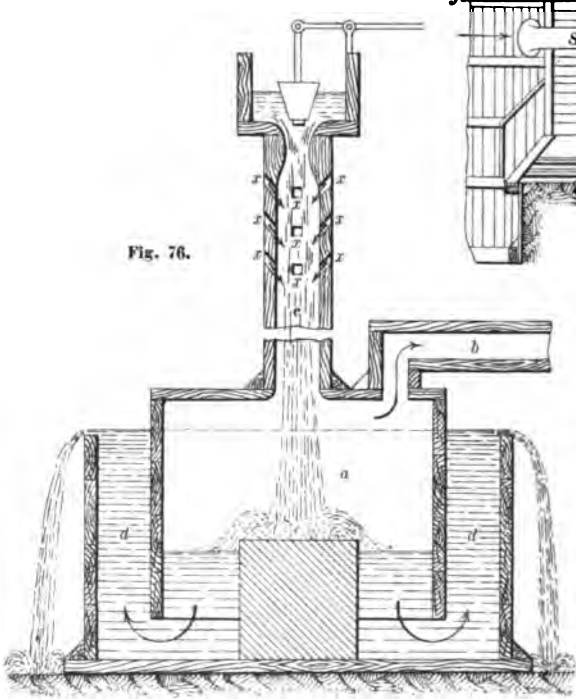
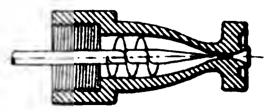


Fig. 74.



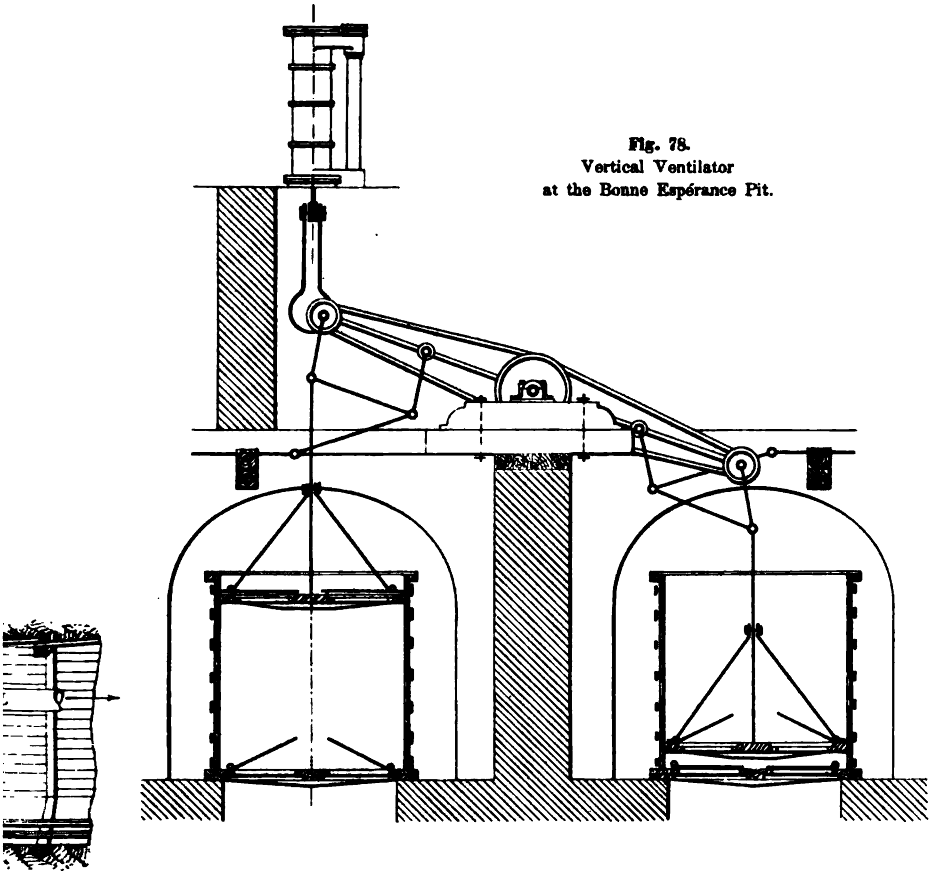


Fig. 78.
Vertical Ventilator at the Bonne Espérance Pit.

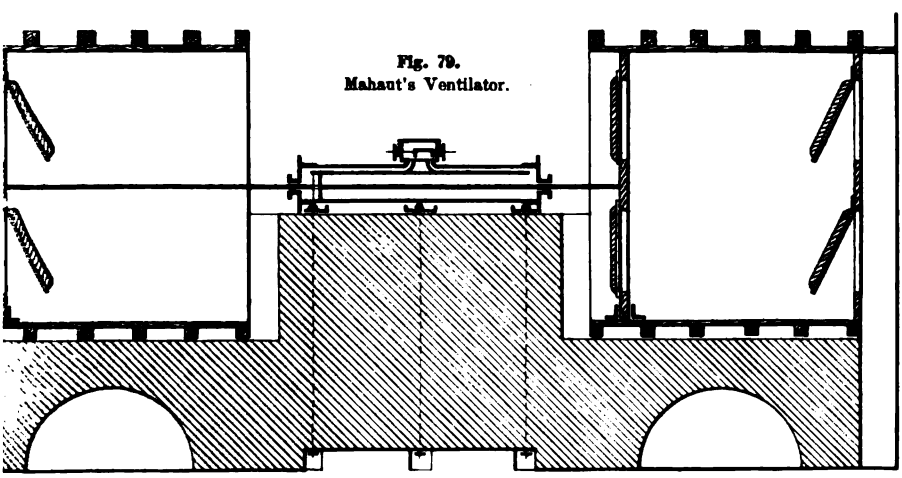


Fig. 79.
Mahaut's Ventilator.

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Fig. 77.

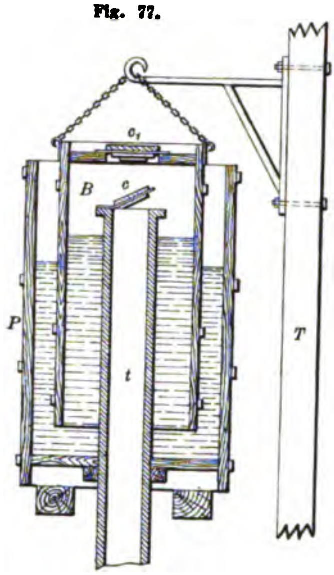

Fig. 80.
Grand Buison Ventilator.

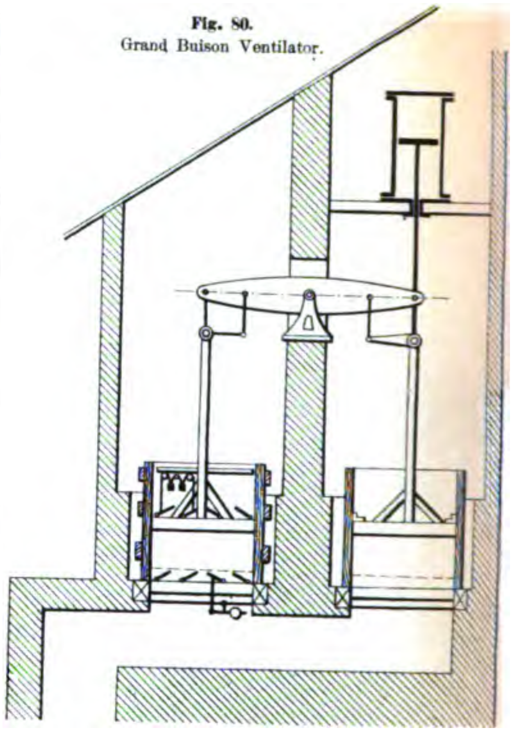

Fig. 84.
De Vaux
Bell Ventilator.

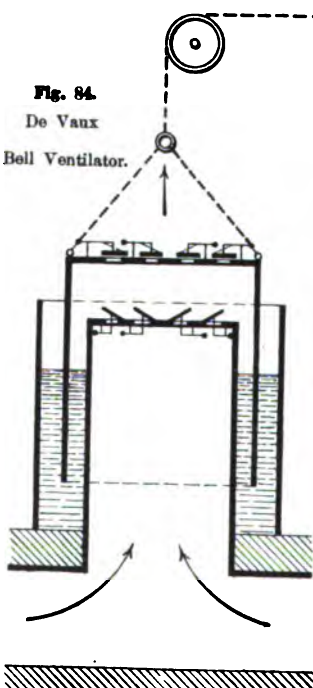

Fig. 82.
Nixon's Ventilator.

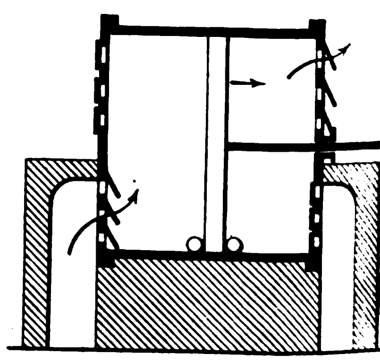

Fig. 81.
Deschamps' Ventilator.

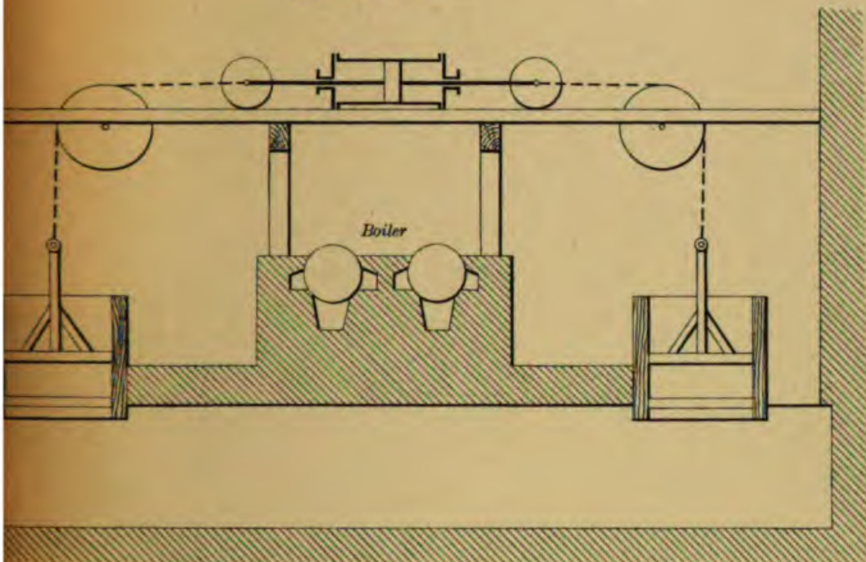

Fig. 83.
Struve's Bell Ventilator.

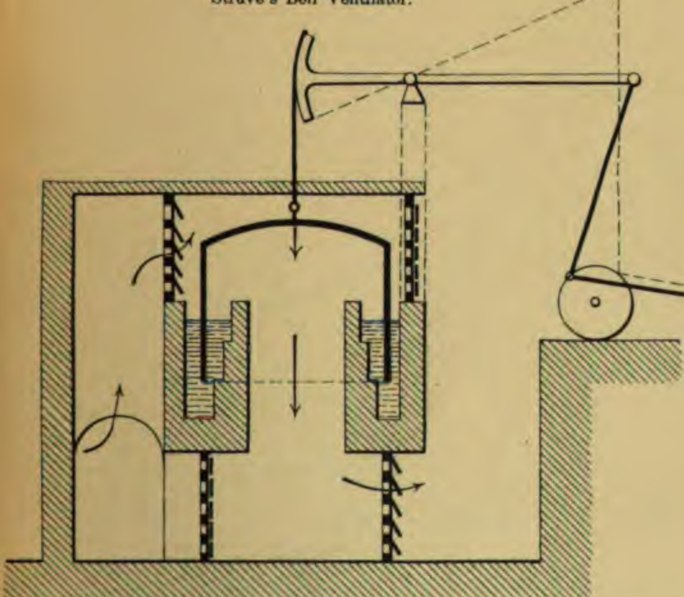

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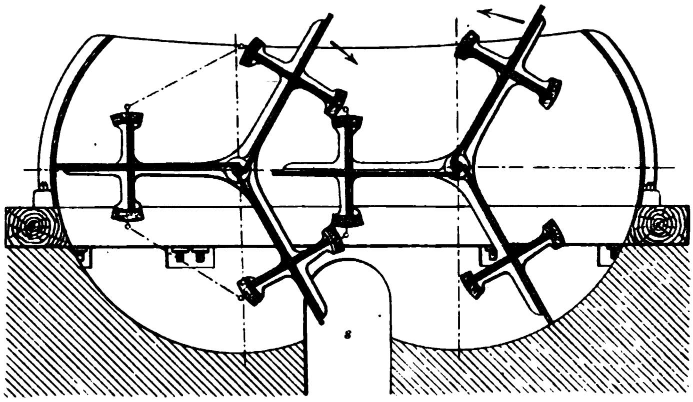
Fig. 86.
Fabry's Ventilator



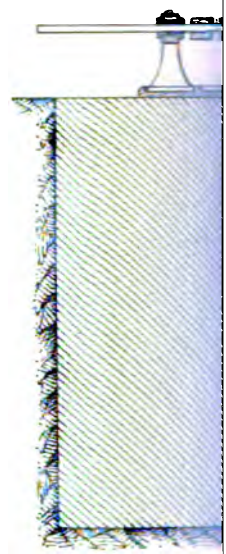


Fig. 88.

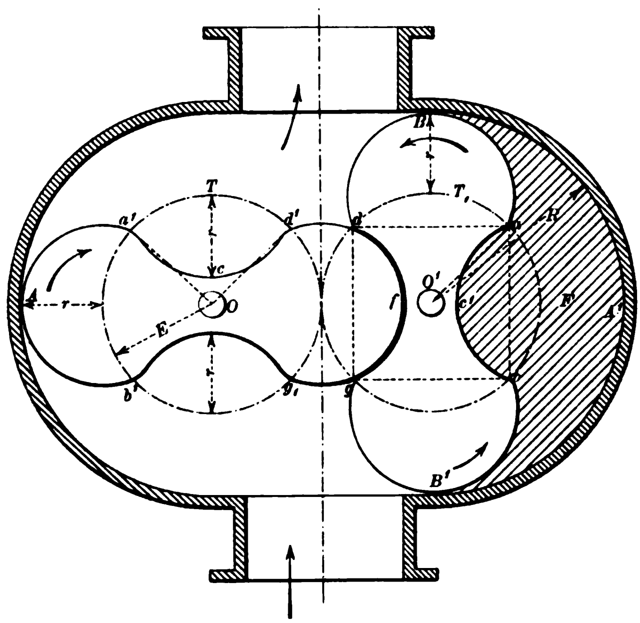
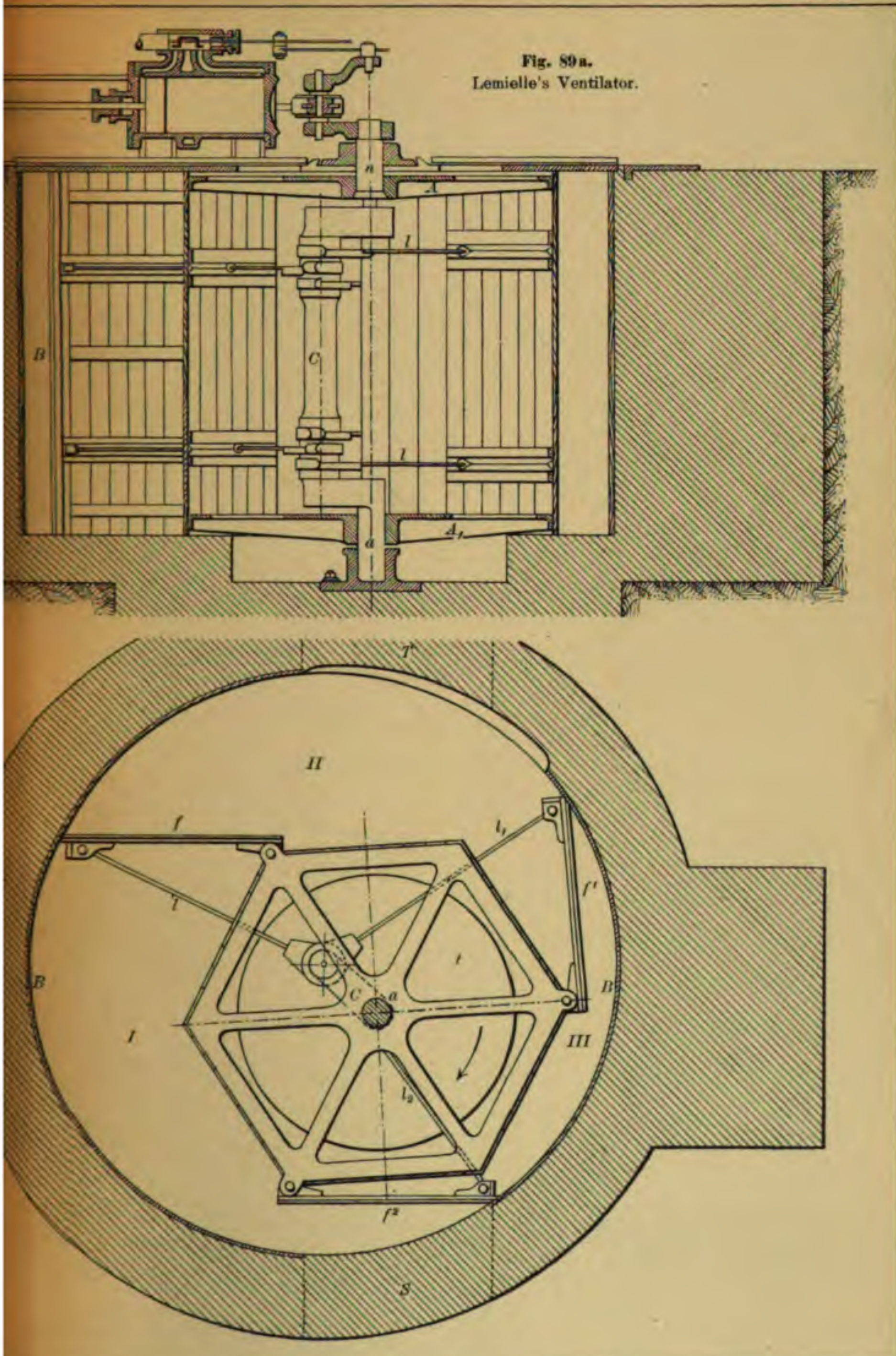


Fig. 89 b.

Fig. 89 a.
Lemielle's Ventilator.



Specially printed for Scott, Greenwood & Co.

Fig. 92a.

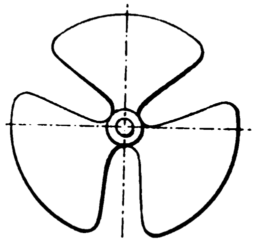


Fig. 90a.

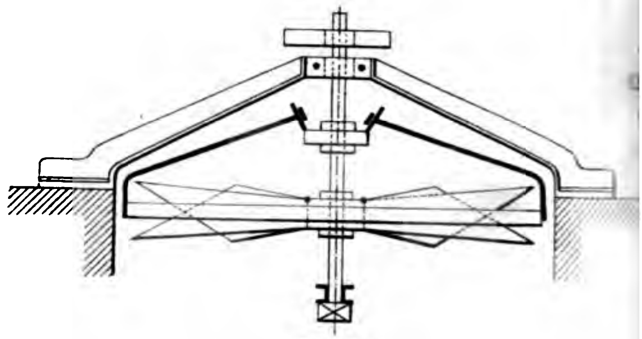


Fig. 92b.

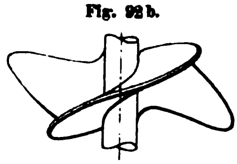


Fig. 90b.

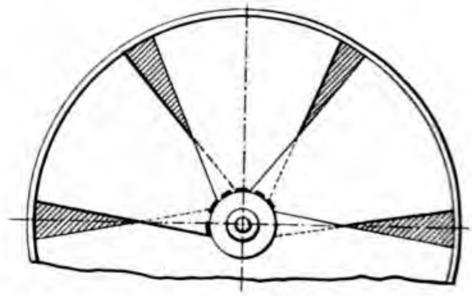


Fig. 91.

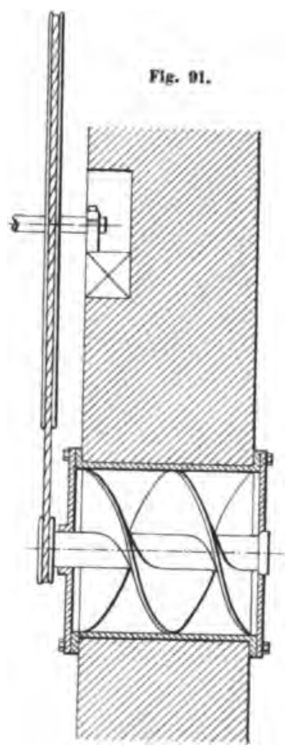


Fig. 94a.

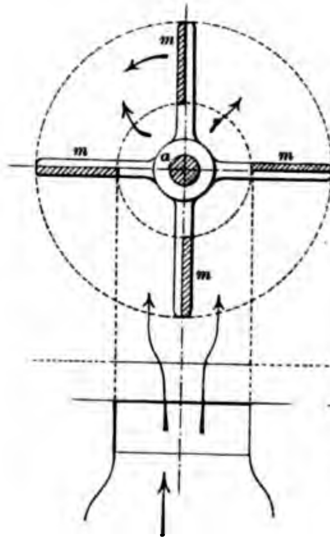
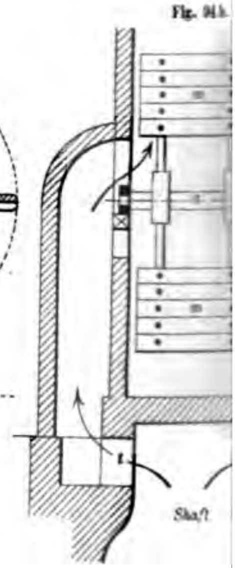


Fig. 94b.



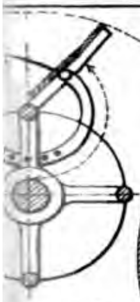


Fig. 93 a.

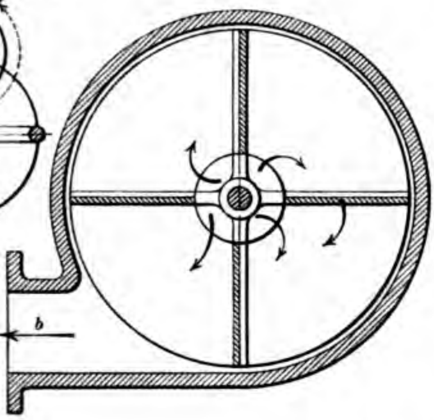


Fig. 93 b.

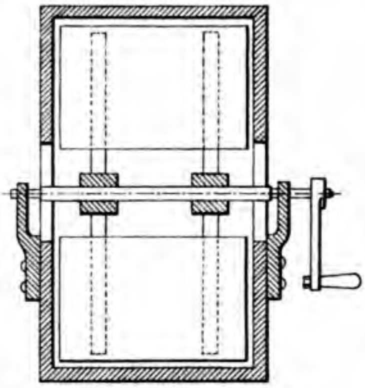


Fig. 95 b.

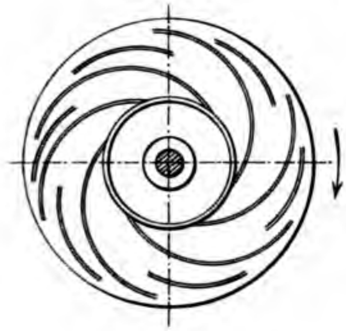
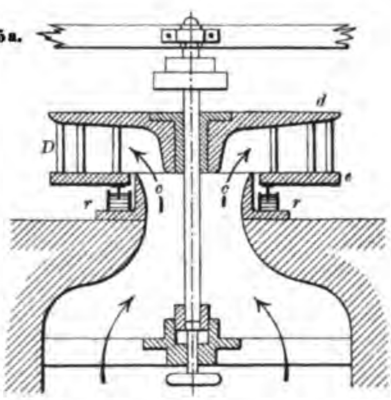


Fig. 95 a.



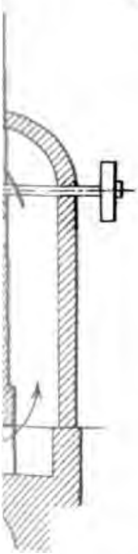


Fig. 97 a.

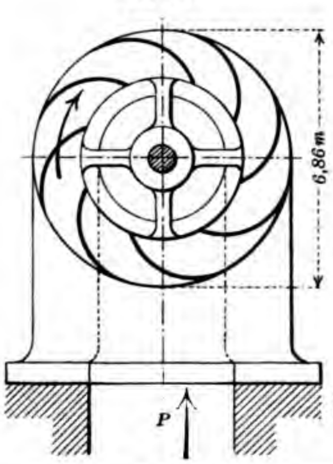


Fig. 97 b.

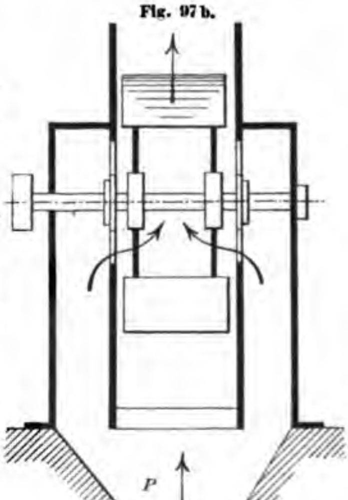


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Fig. 100a.

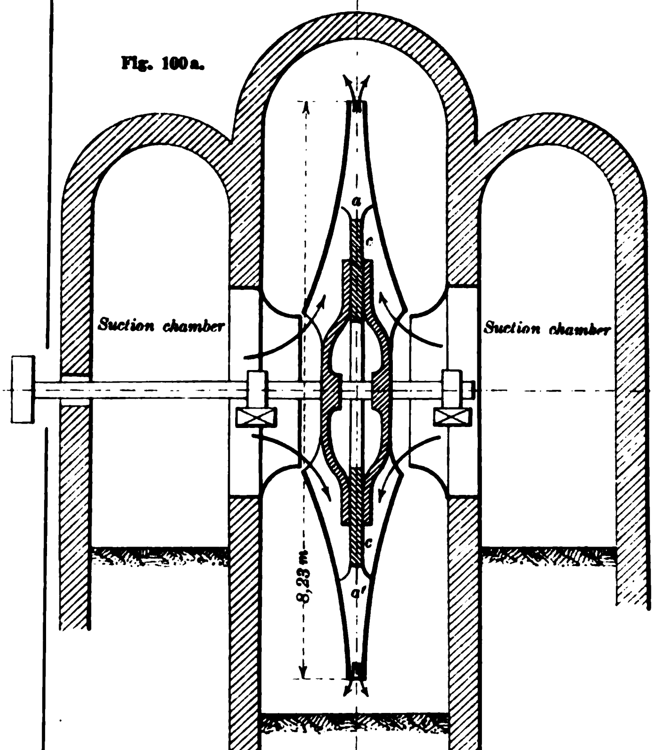

Fig. 100b.

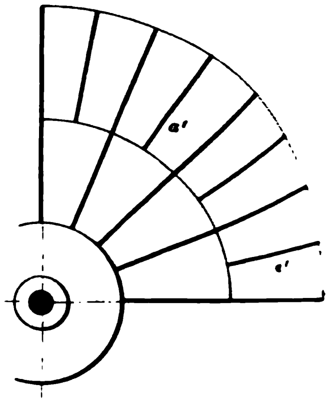

Fig. 99a.

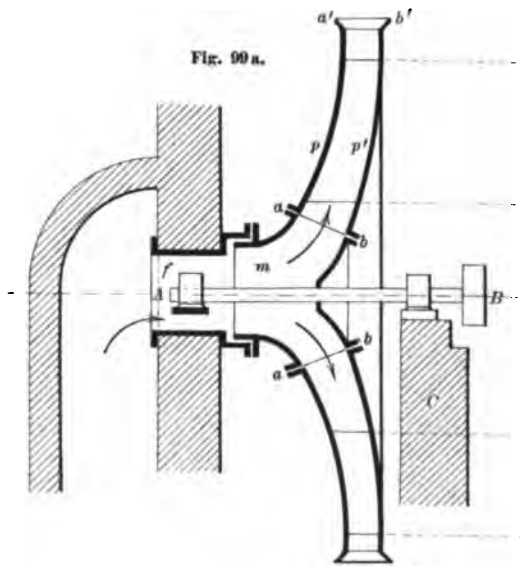

Fig. 99b.

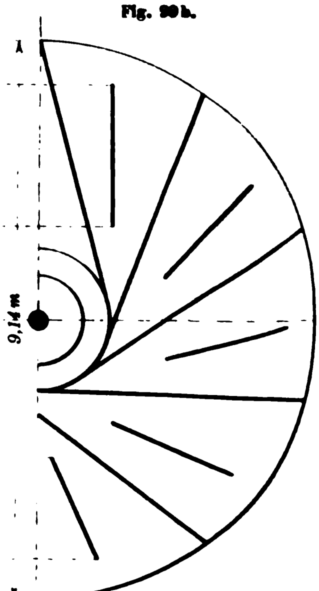

Fig. 101 a.
Rittinger's Ventilating Fan.

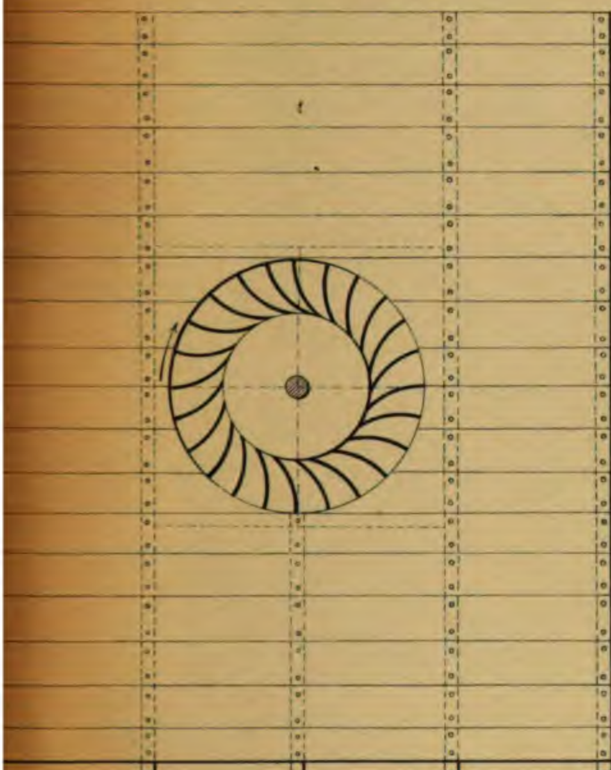

Fig. 101 b.

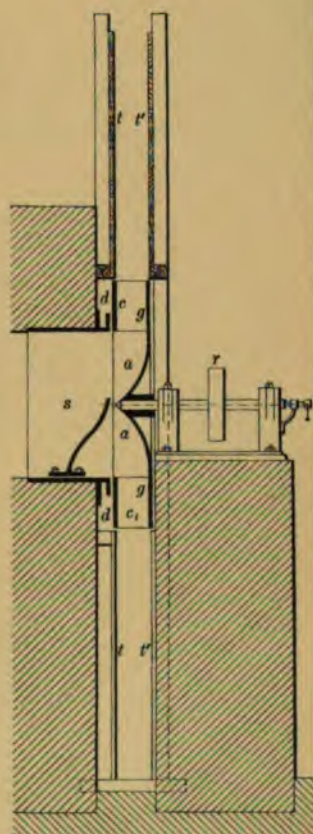

Fig. 98 a.

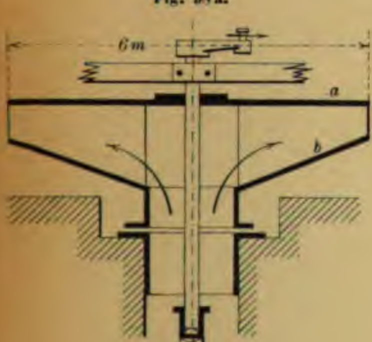

Fig. 98 b.

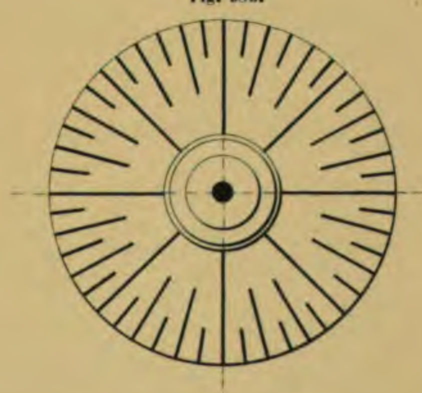

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Fig. 102.
Harzé's Ventilating Fan.

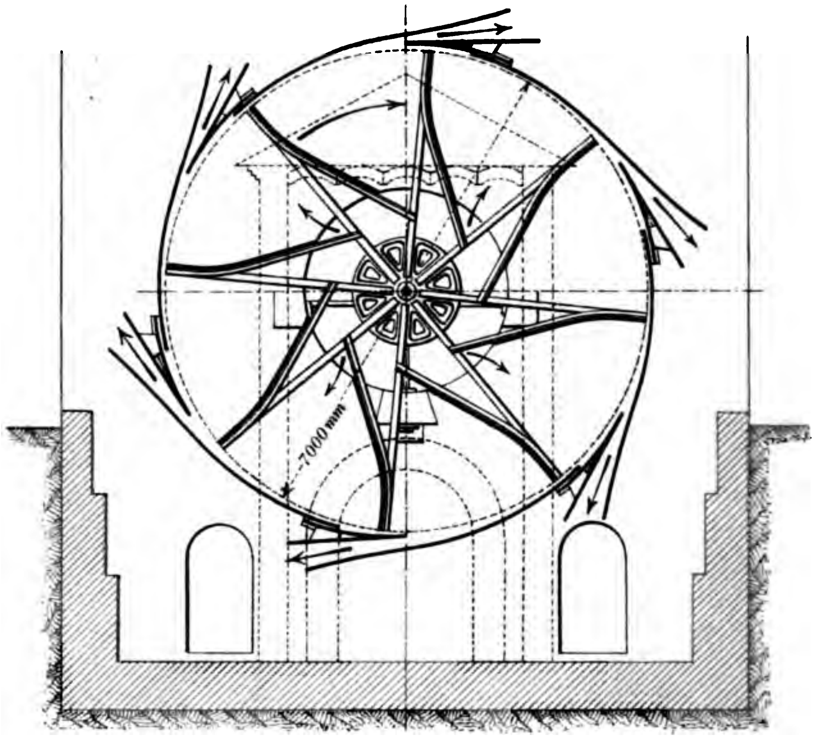


Fig. 102 a.
Rittinger Centrifugal Fan at Mont-Cenis.

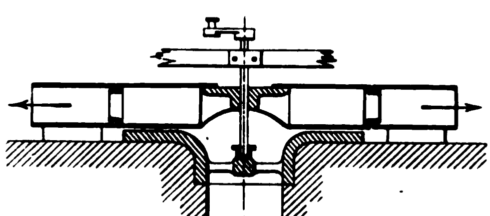
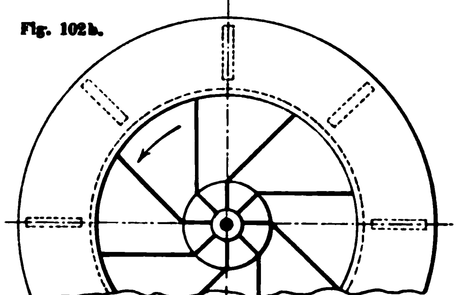


Fig. 102 b.



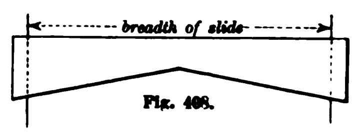


Fig. 406.

Fig. 407.

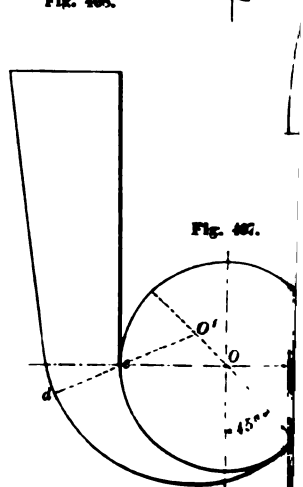


Fig. 104a.
Kraft's Turbine Ventilator.

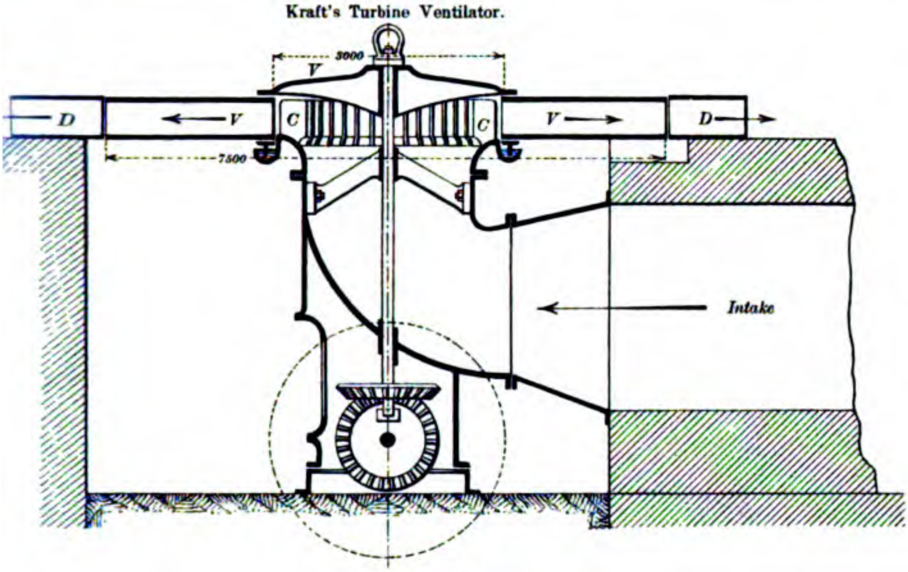


Fig. 104b.

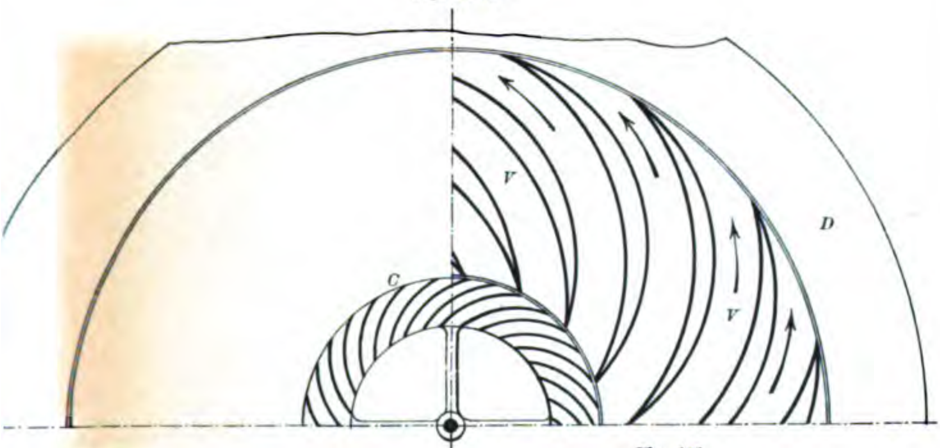


Fig. 106.

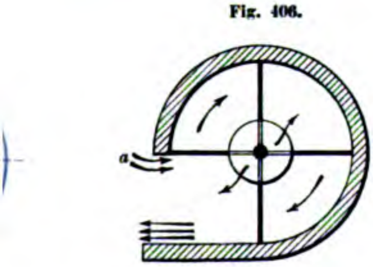


Fig. 105.

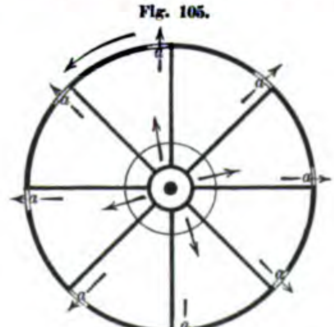


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Fig. 110 c.

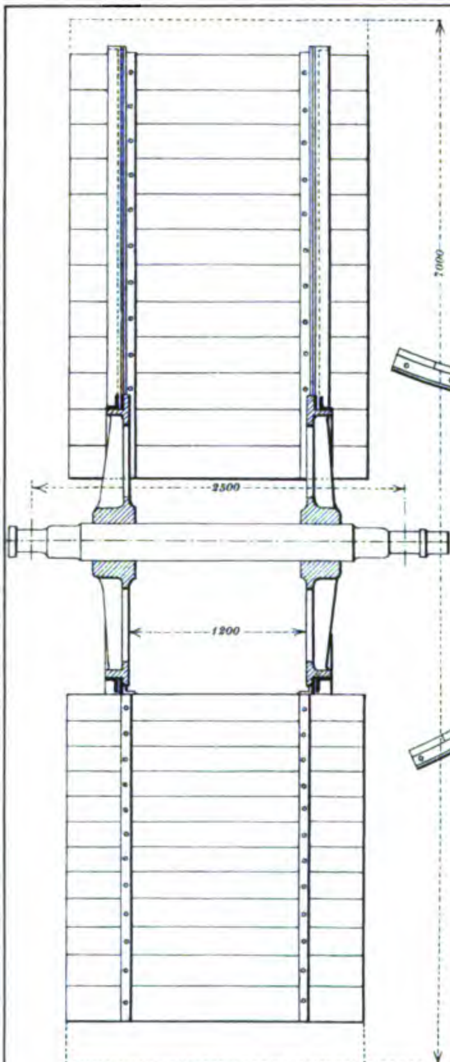


Fig. 110 d.

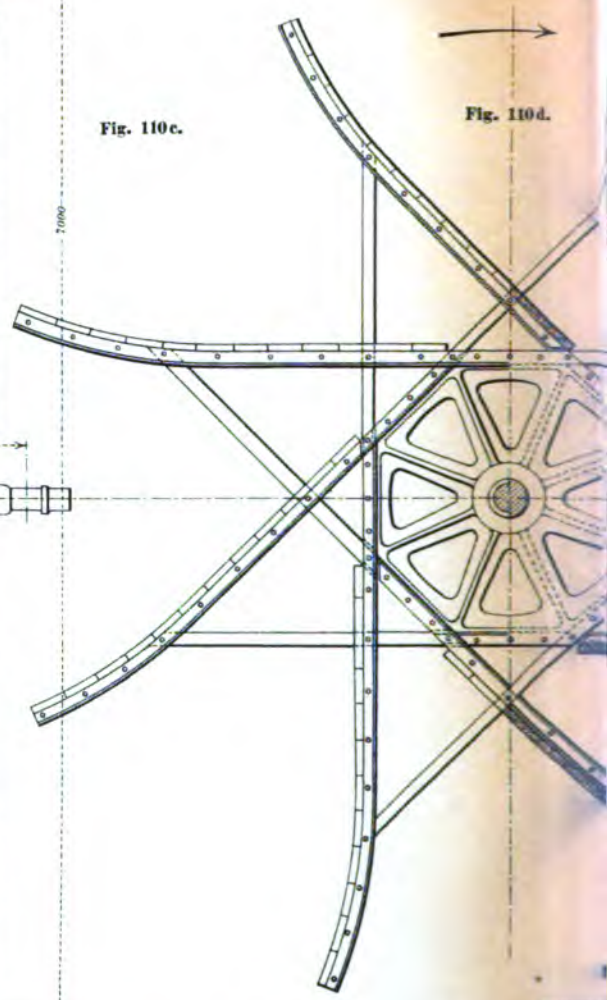


Fig. 109 e.

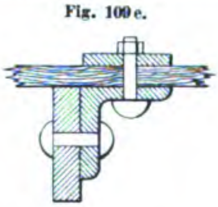
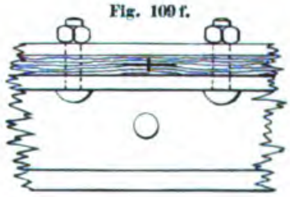


Fig. 109 f.



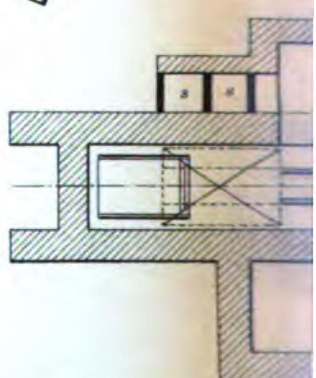


Fig. 109 g.

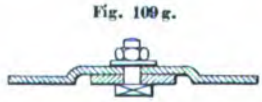


Plate XVIII.

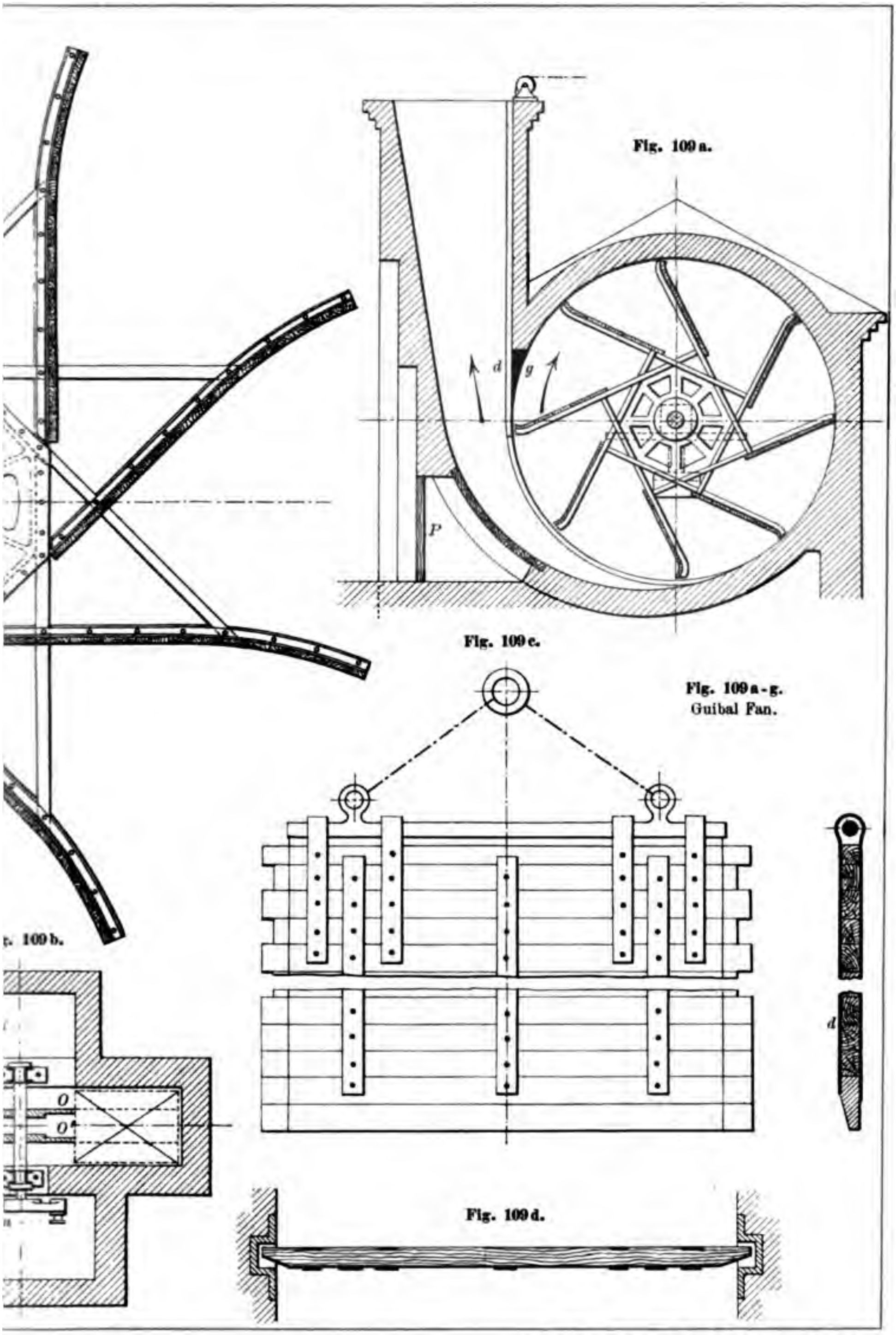


Fig. 109 a.

Fig. 109 c.

Fig. 109 a-g.
Guibal Fan.

Fig. 109 b.

Fig. 109 d.

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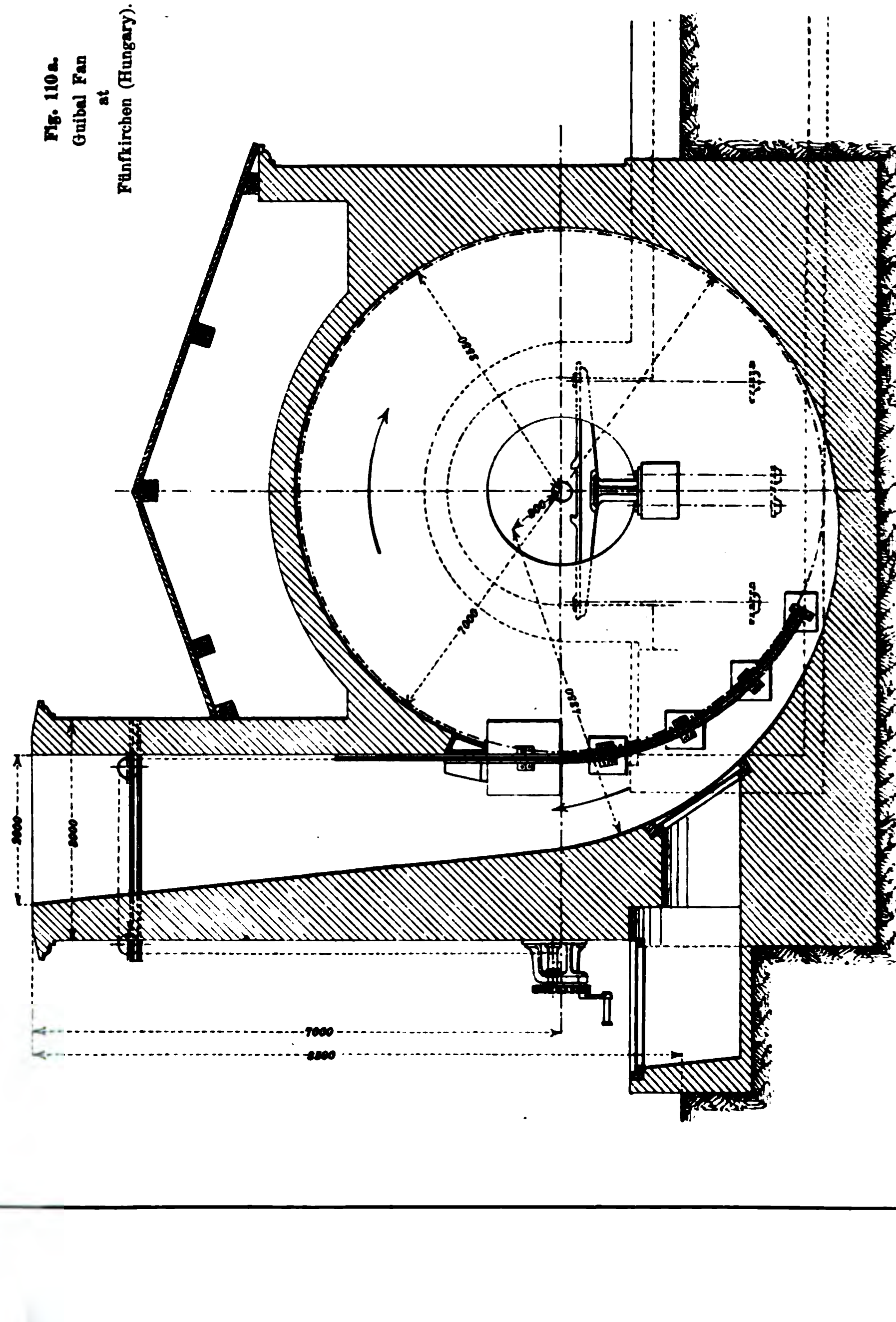

Fig. 110 a.
Guibal Fan
at
Fünfkirchen (Hungary).

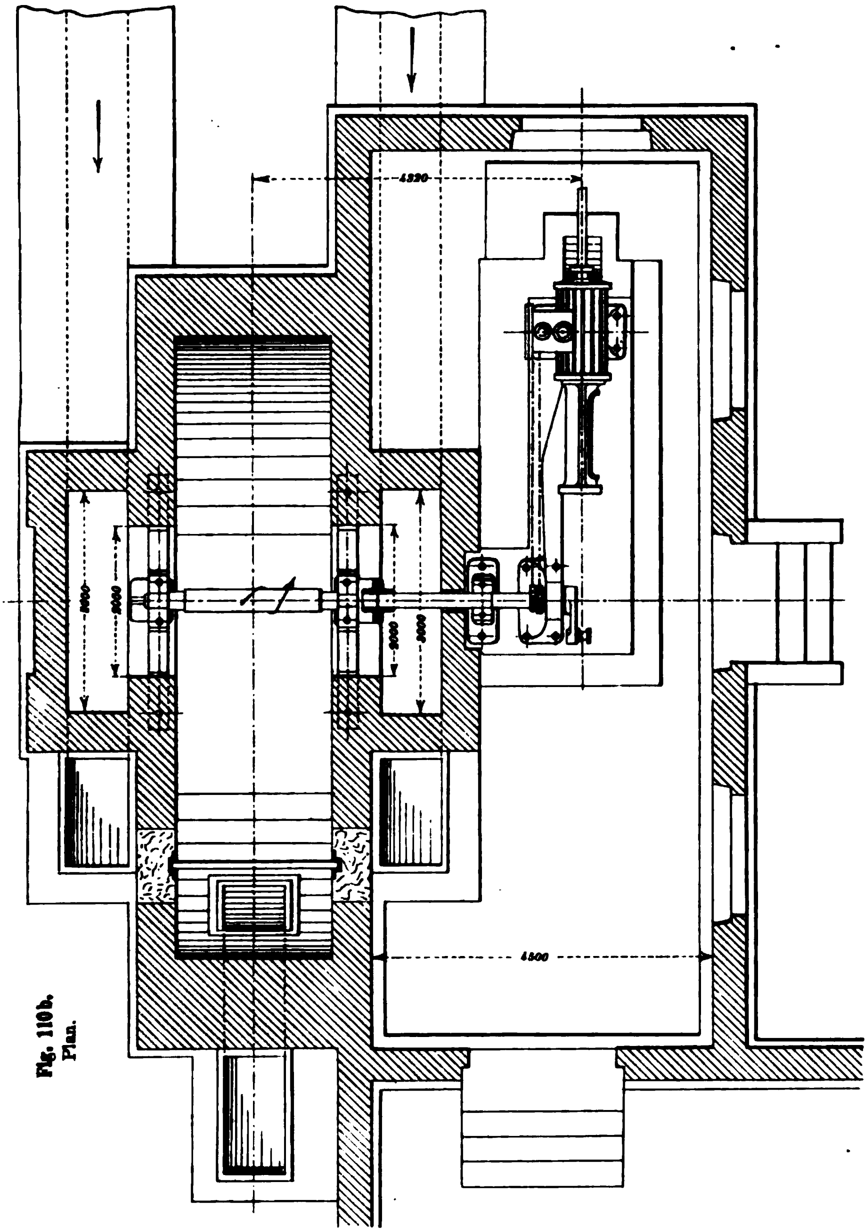

Fig. 110b.
Plan.

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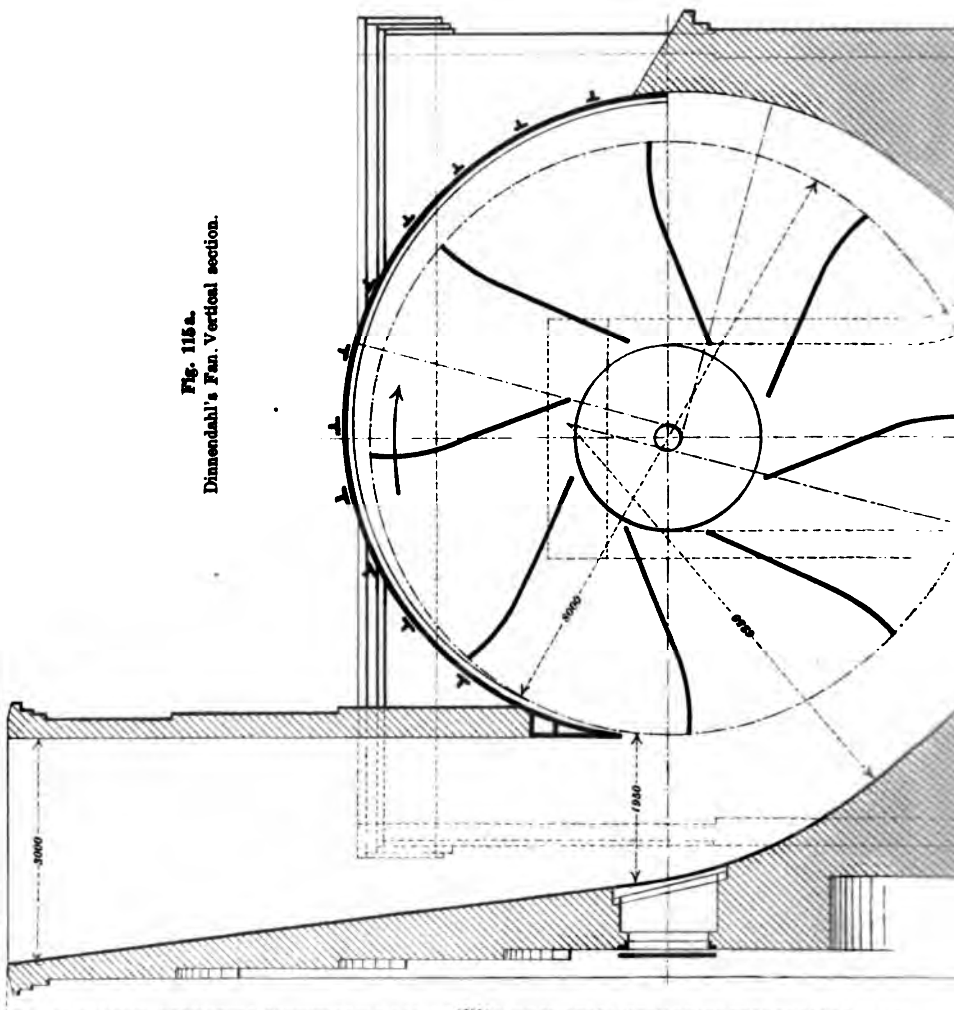

Fig. 115a.
Dinnendahl's Fan. Vertical section.

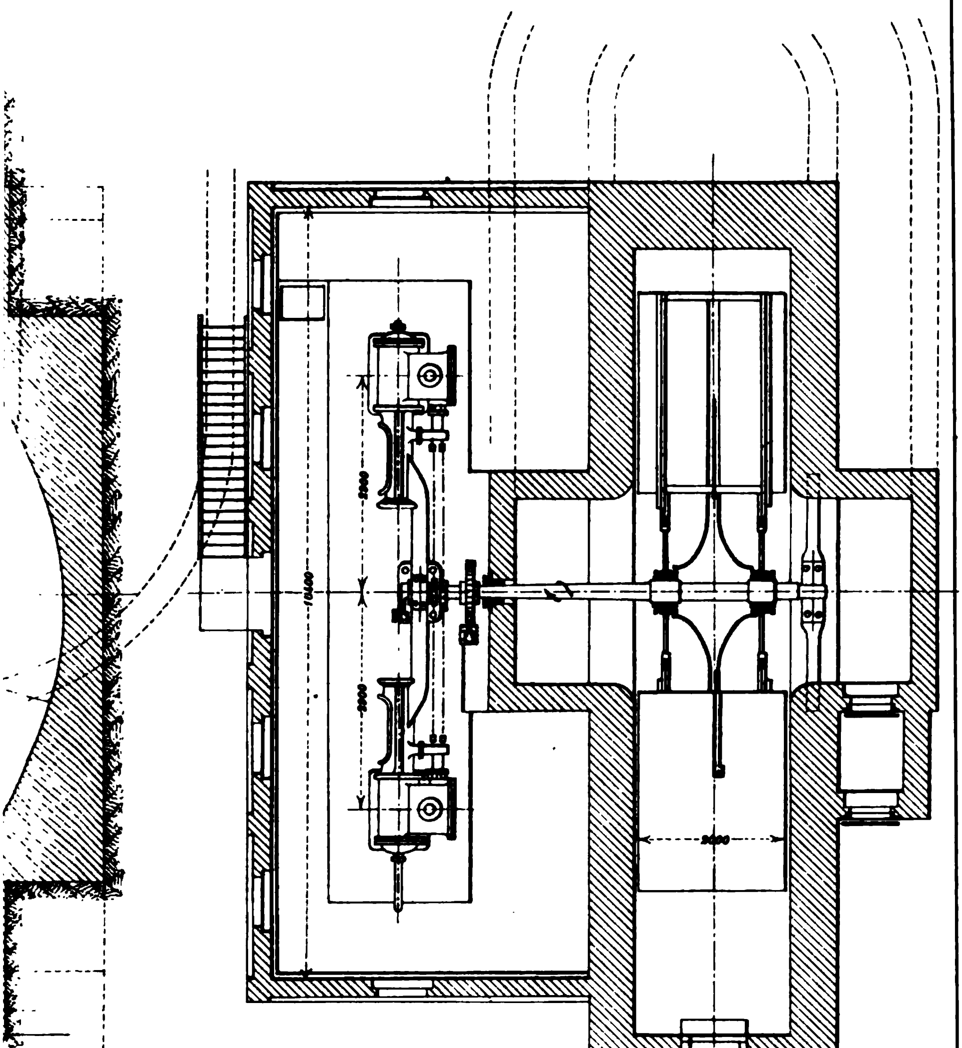

Fig. 135 b.
Plan.

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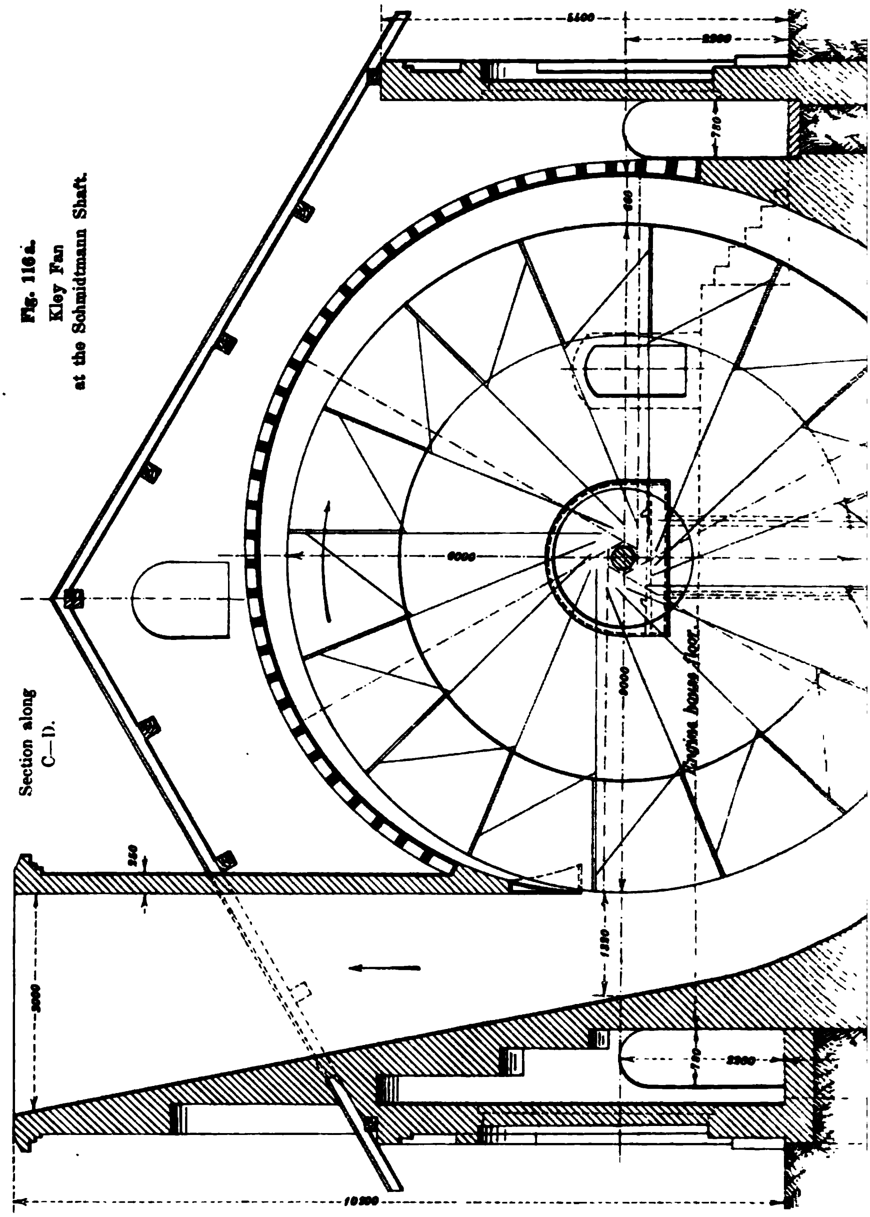

Fig. 116a. Kley Fan at the Schmidtmann Shaft.

Section along C—D.

Plate XXI.

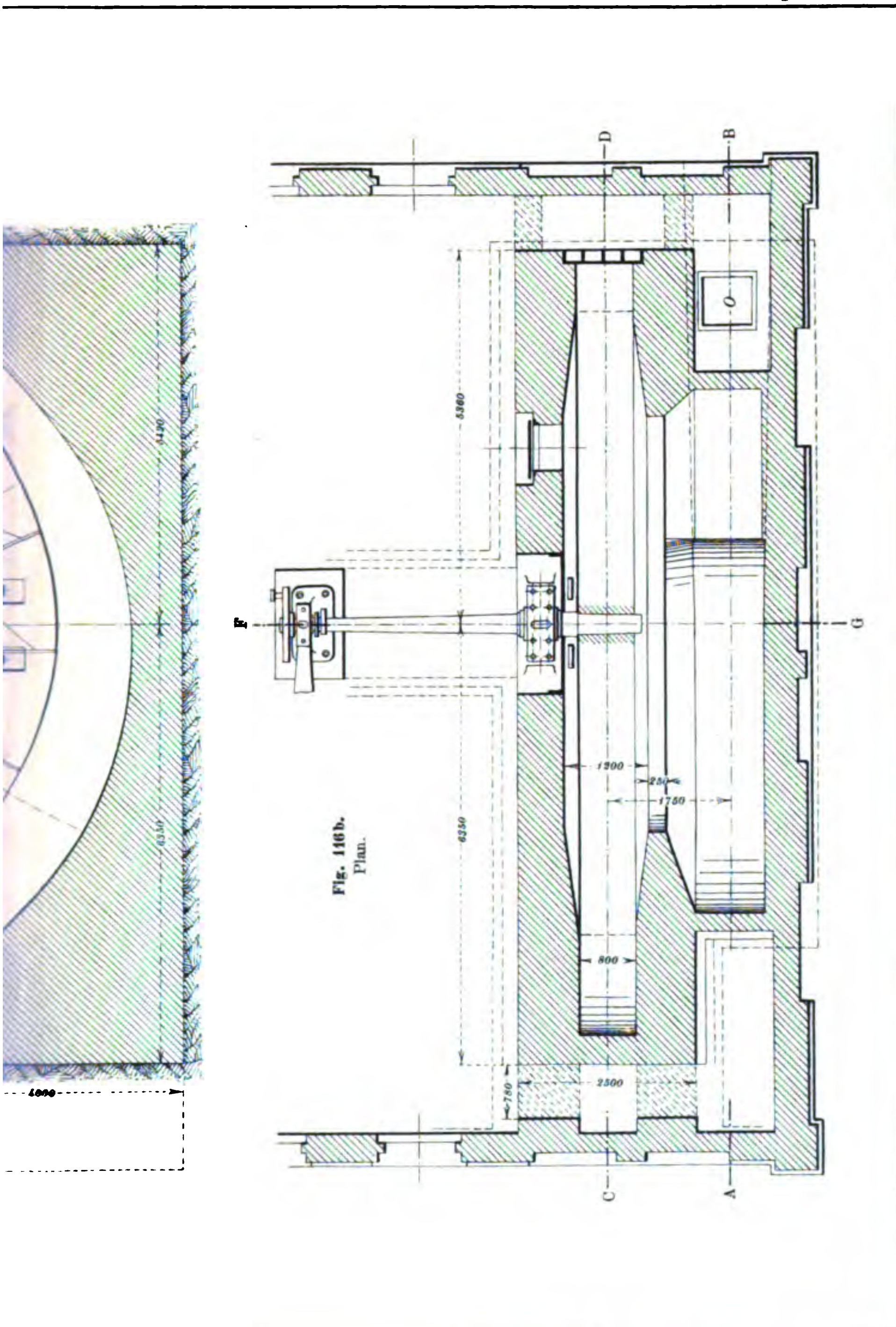

Fig. 116b.
Plan.

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Fig. 116 d.
Section along A-B.
(Plate XXI)

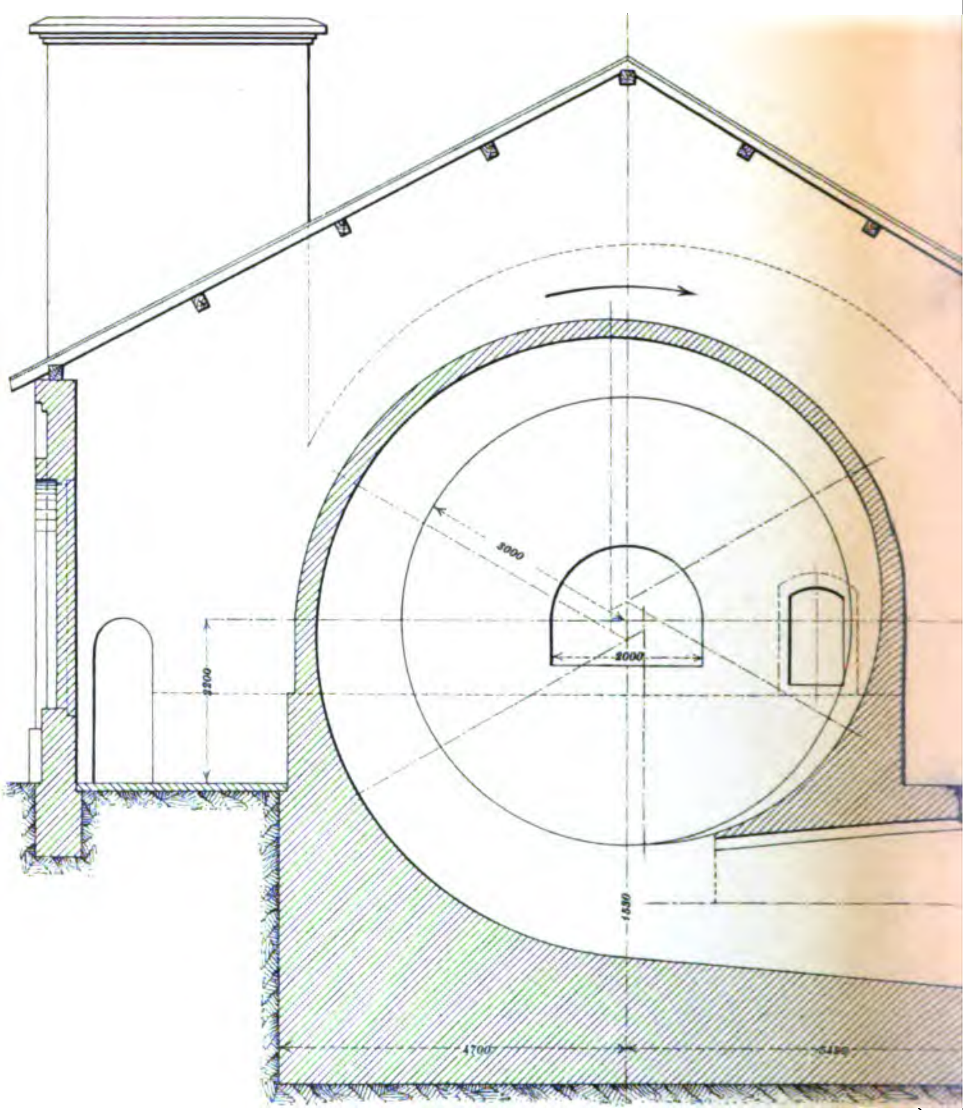
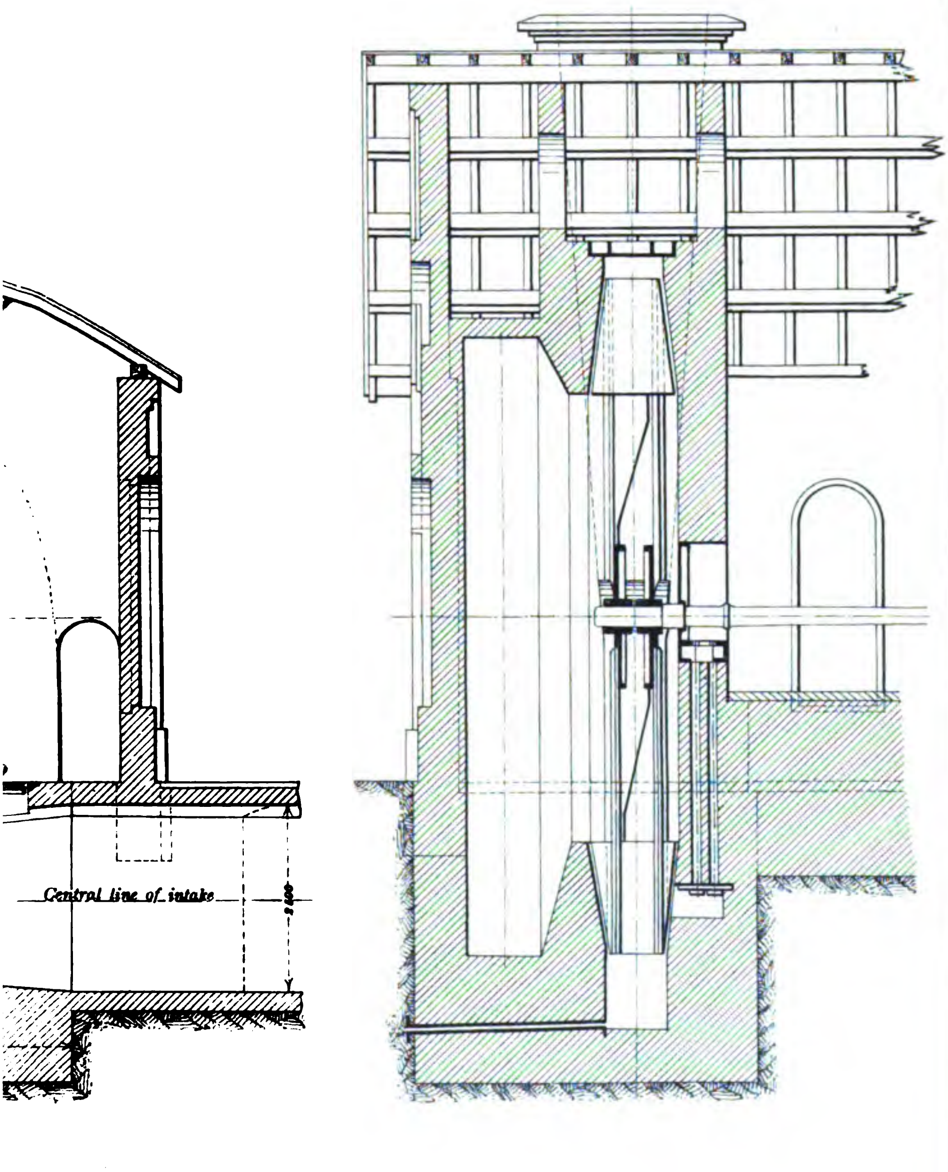


Fig. 116 c.
Section along G-F.
(Plate XXI)



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Wabner, Ventilation in Mines.

Fig. 117 a.

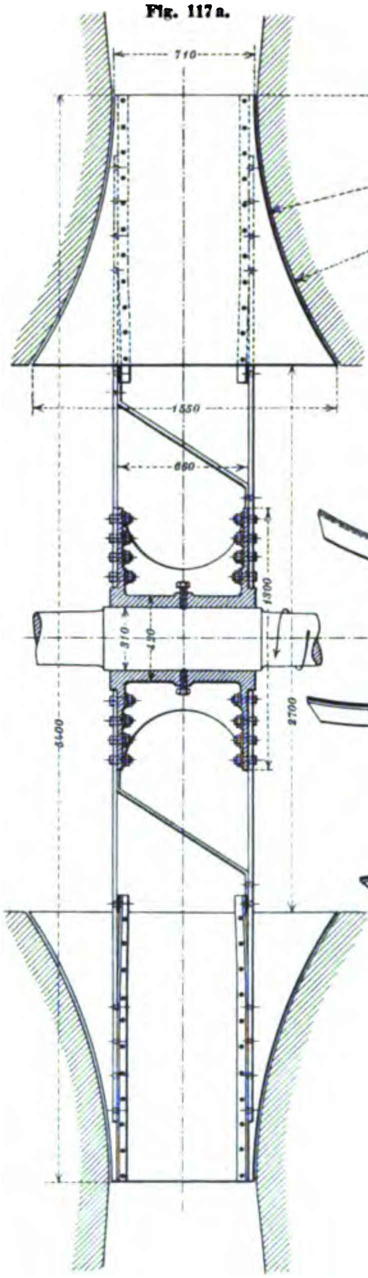
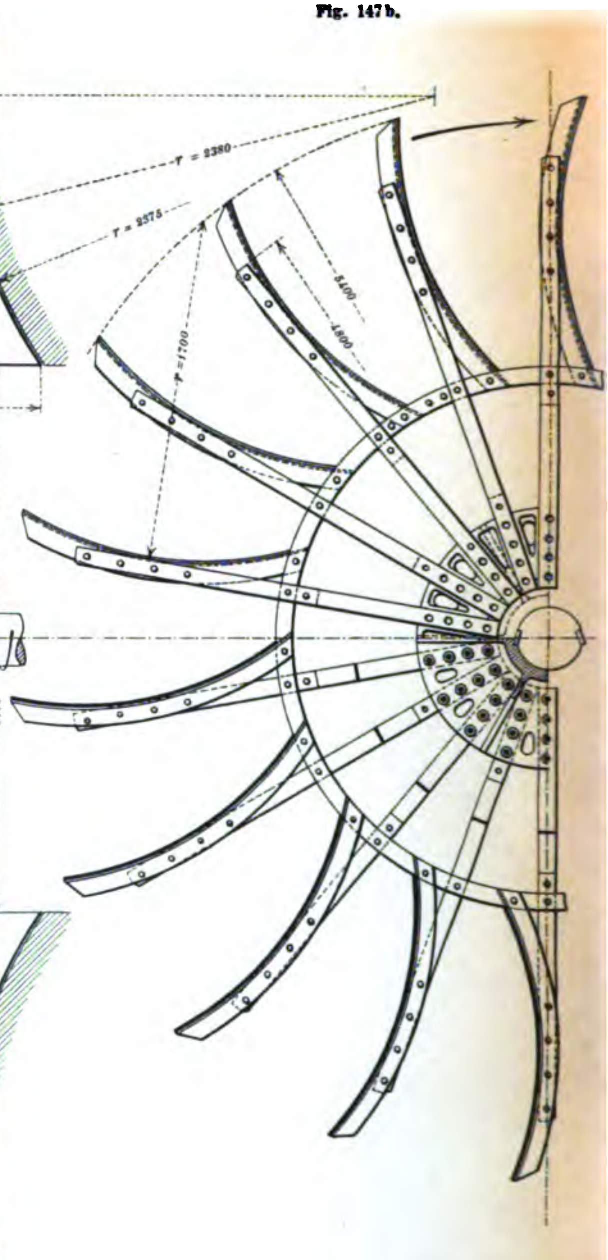


Fig. 147 b.



Pelzer Fan. (Fig. 119 a - c).

Fig. 119 c.
Section along m - n of Fig. 119 b.

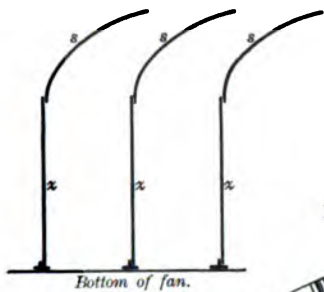


Fig. 449 a.

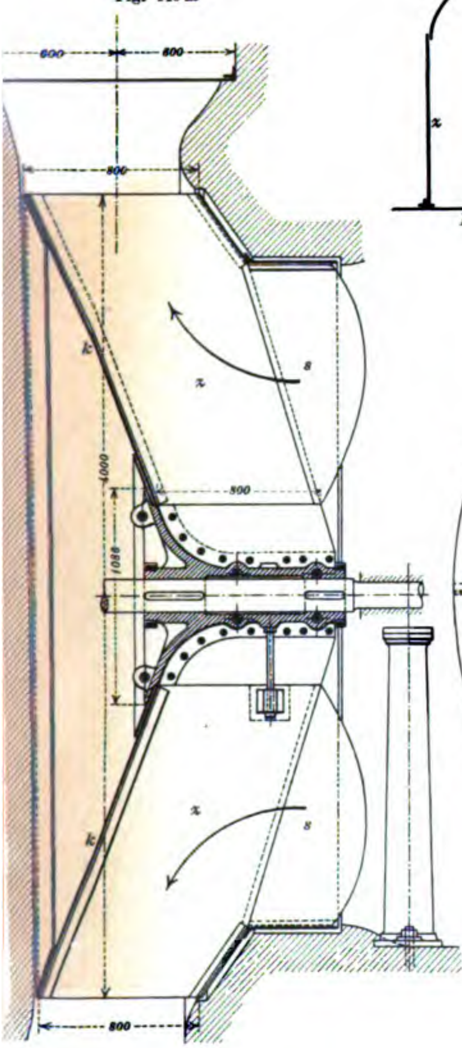
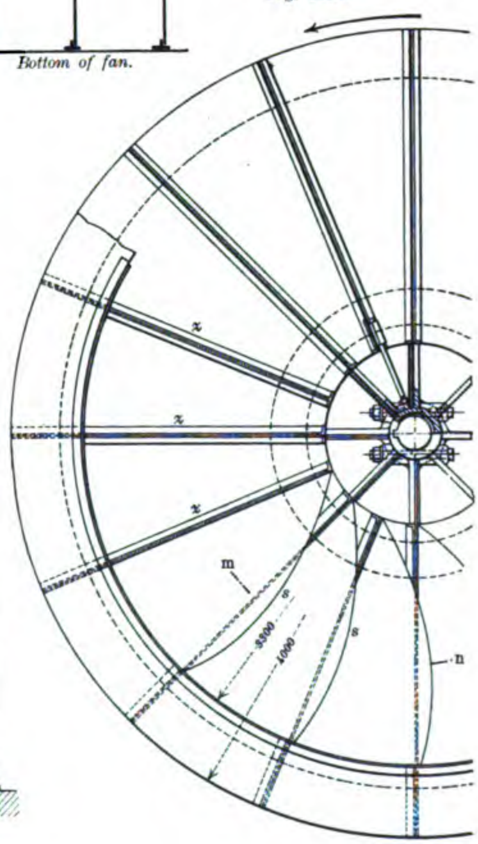


Fig. 449 b.



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Wabner, Ventilation in Mines.

Fig. 118 a. Longitudinal Section A - B.

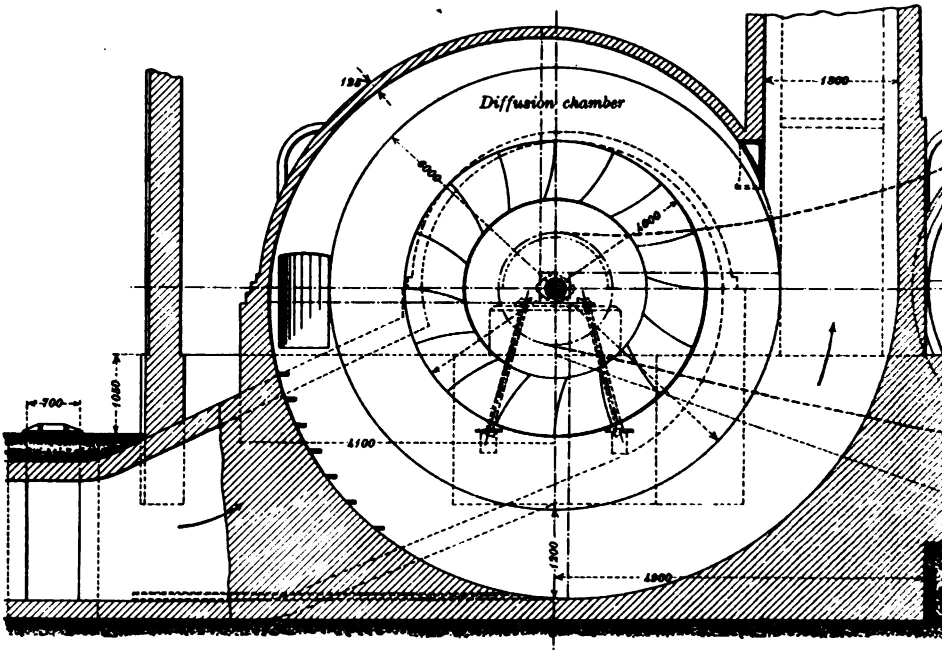
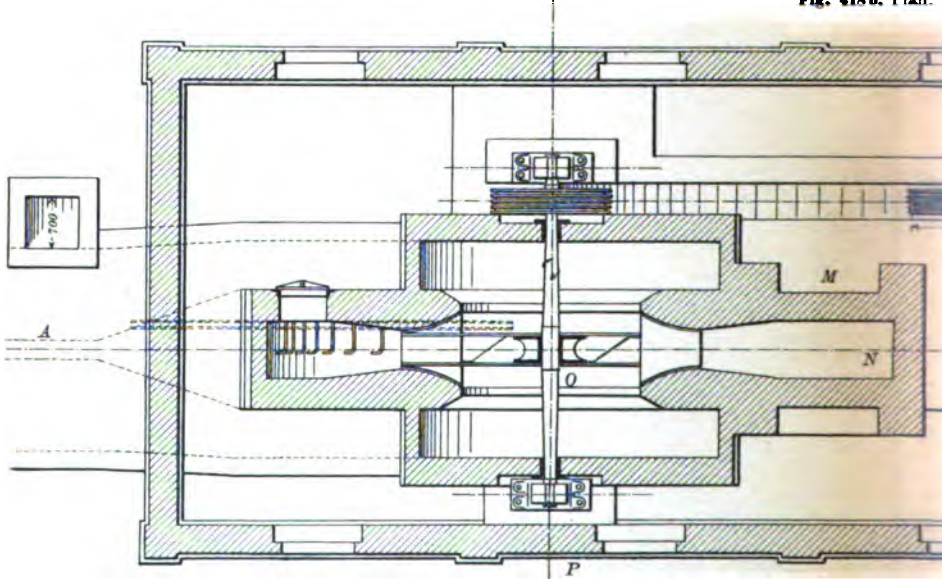
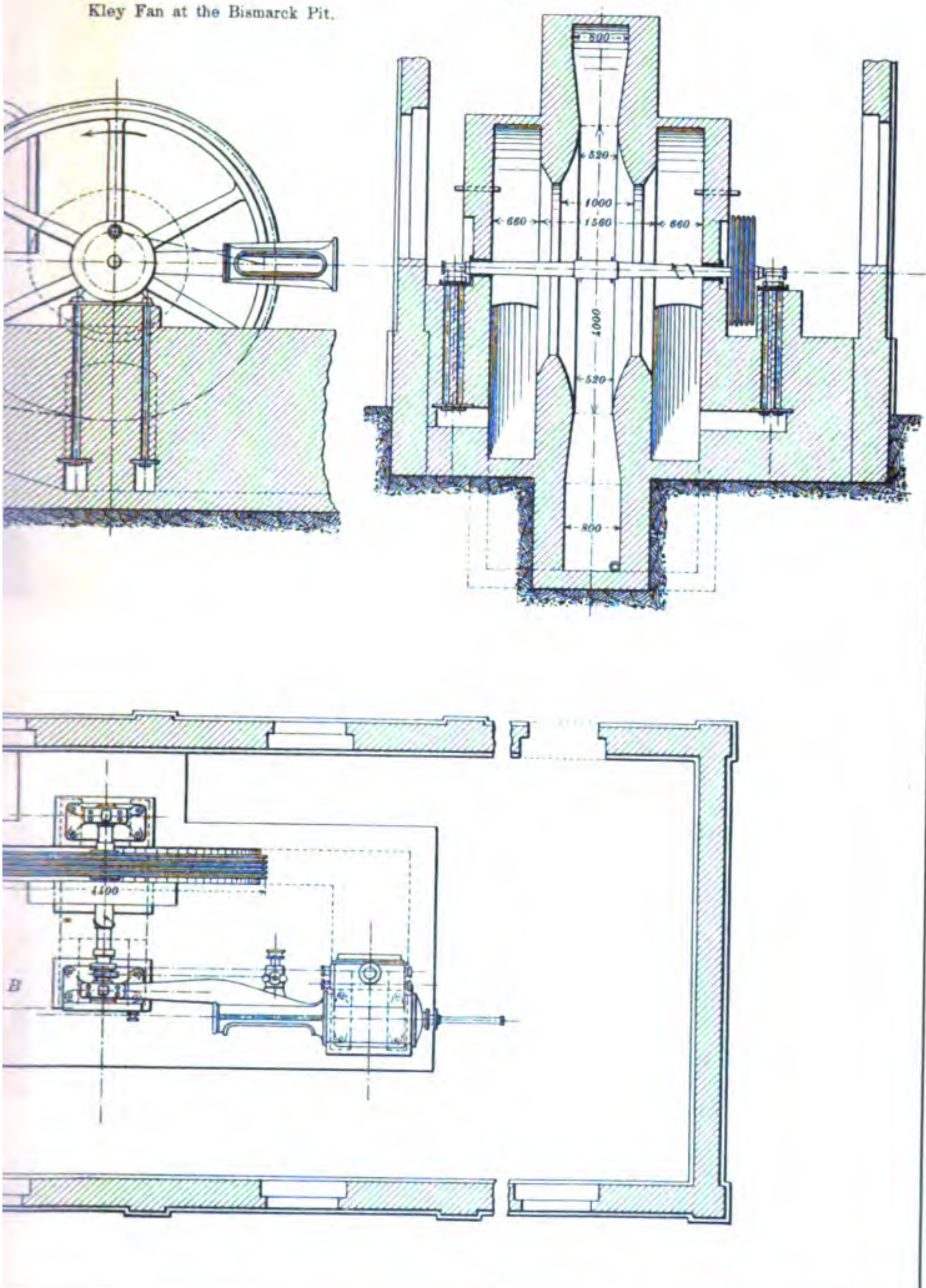


Fig. 418 b. Plan.



Kley Fan at the Bismarck Pit.

Fig. 118c. Cross Section.



Pelzer Fan (Fig. 119 d - f).

Fig. 119 d.

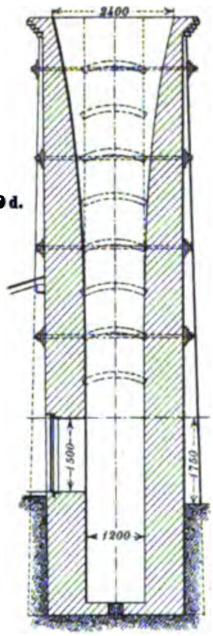
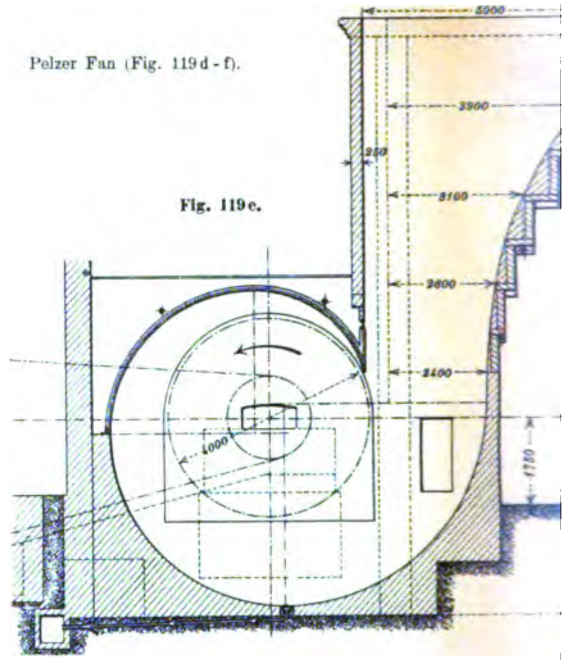


Fig. 119 e.



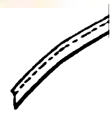


Fig. 120 b.

Geisler Fan (Fig. 126 a - d).

Fig. 120 c.

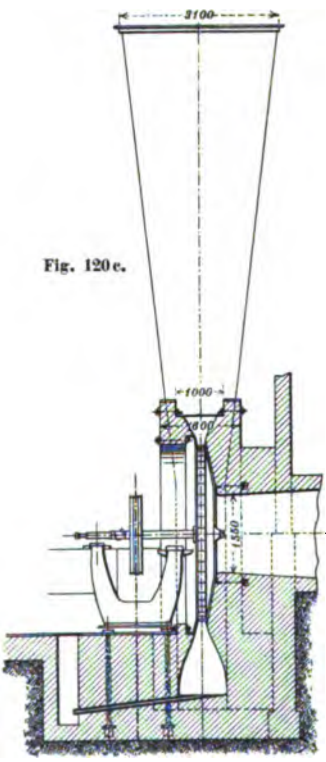
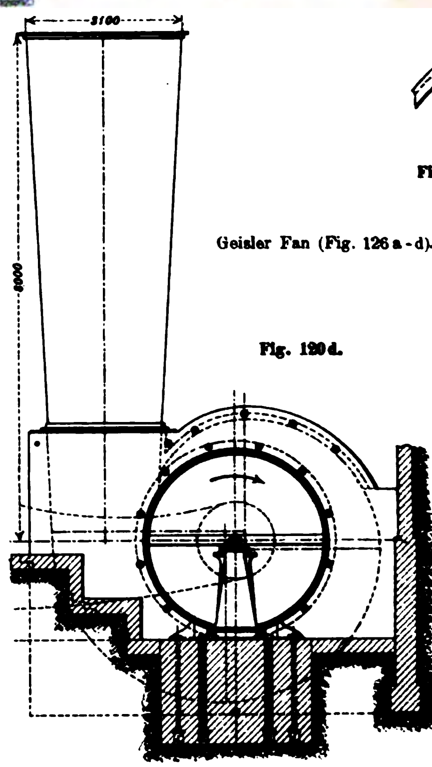
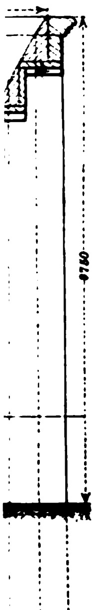


Fig. 120 d.





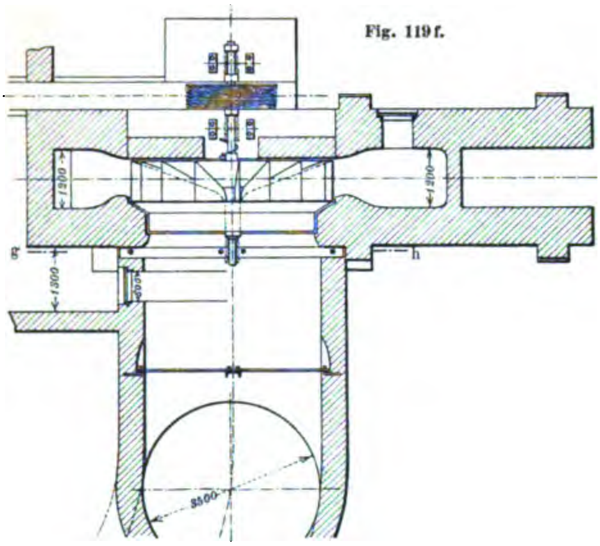
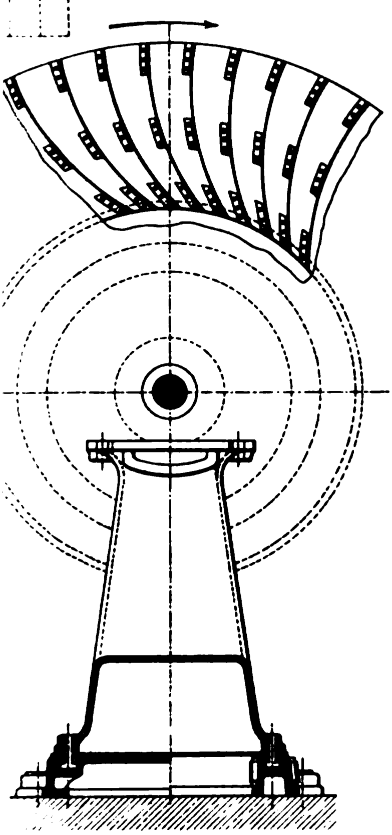


Fig. 119 f.



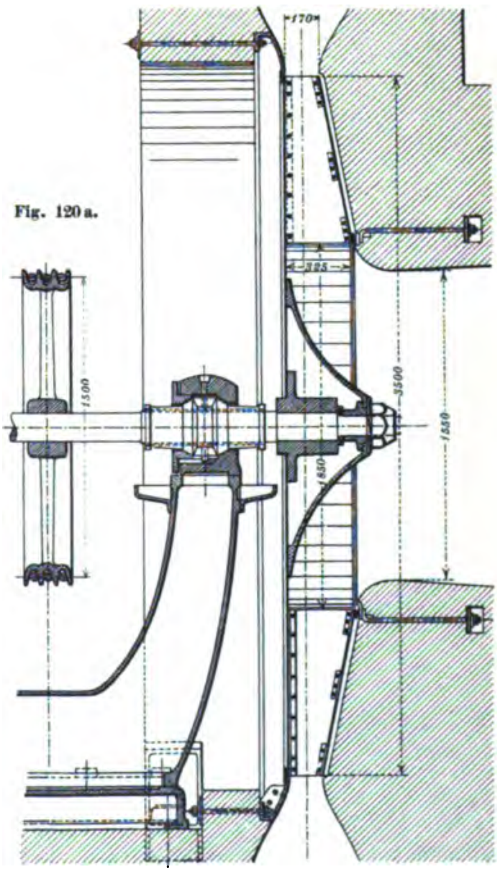


Fig. 120 a.

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Fig. 123a.

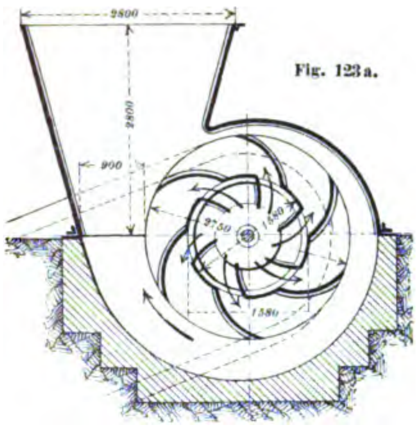
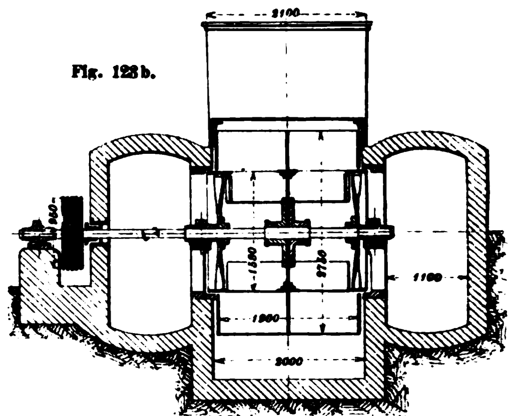


Fig. 123b.



Capell Fan
(Fig. 123a and b).

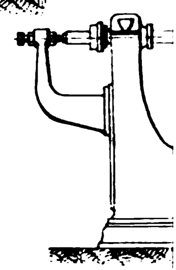


Fig. 121.

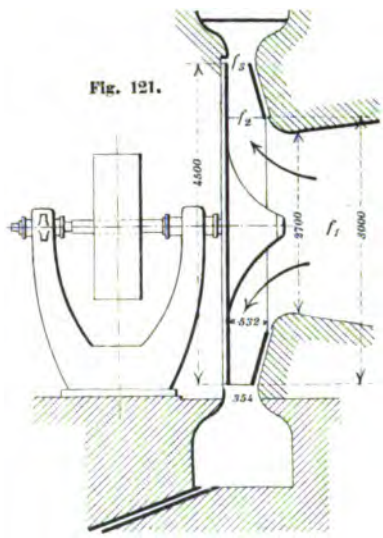
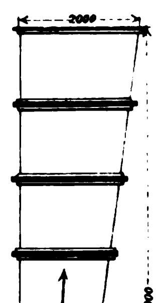


Fig. 124c.



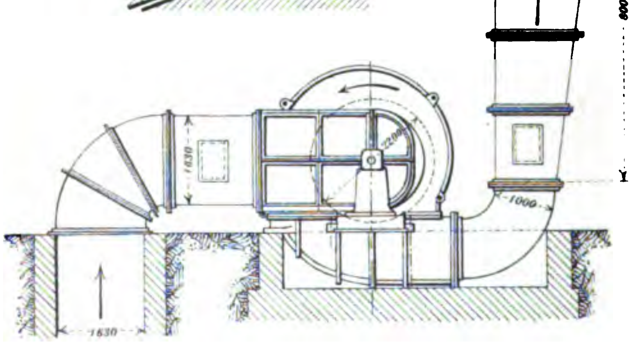
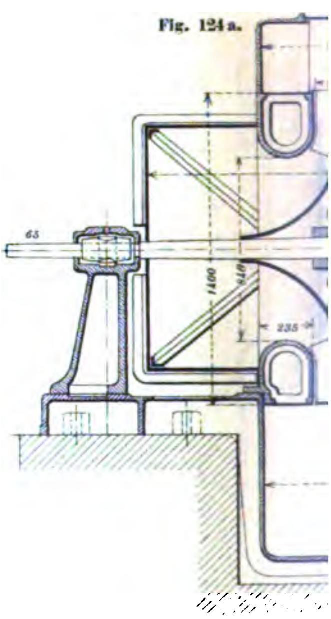
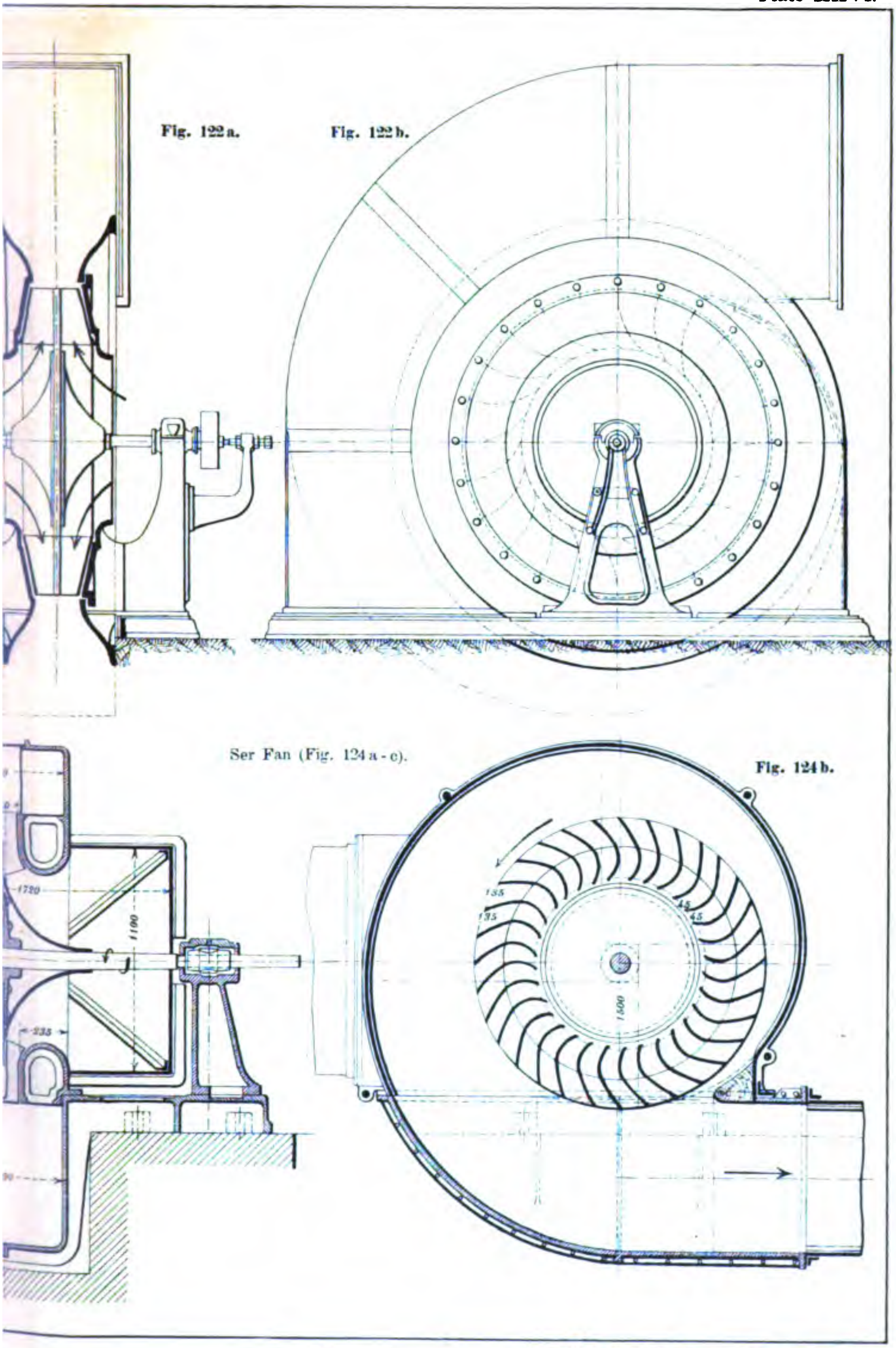


Fig. 124a.





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Hanarte Fan (Fig. 126 a - c).

Fig. 126 a.

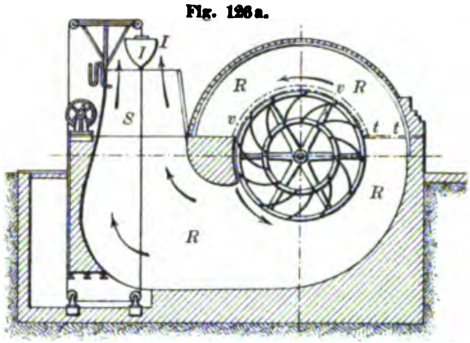


Fig. 126 c.

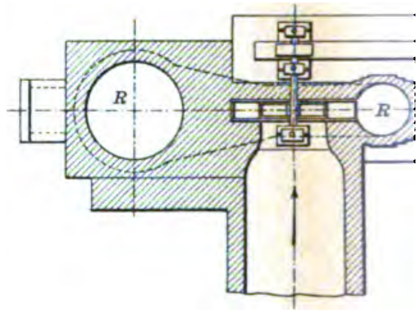


Fig. 126 b.

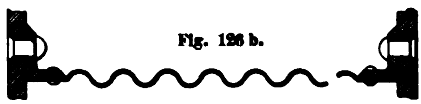
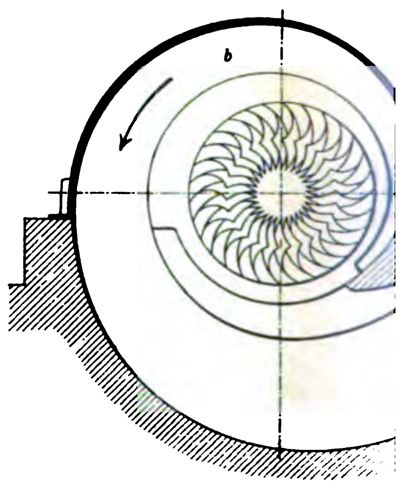


Fig. 125 a.



Mortier Fan (Fig. 128 a u. b)

Fig. 128 a.

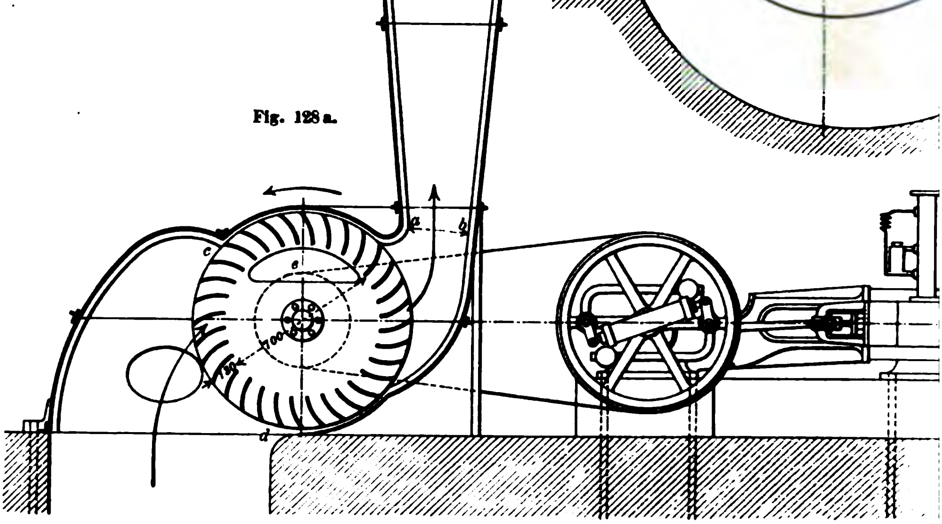
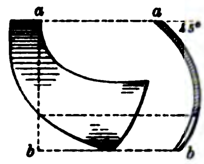
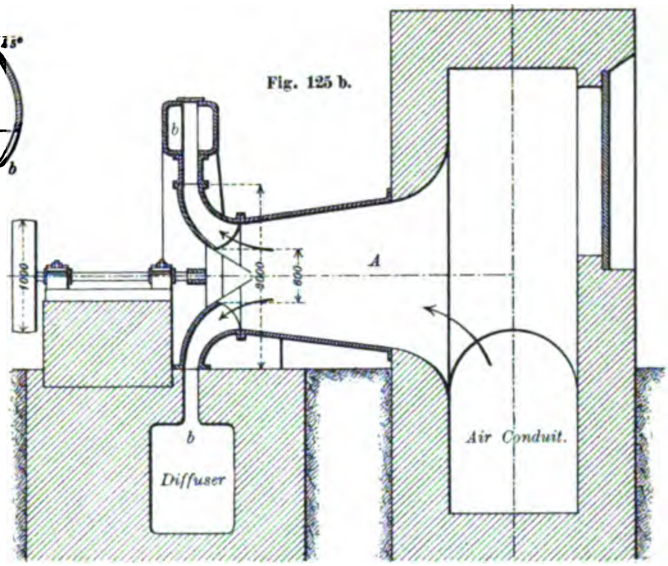


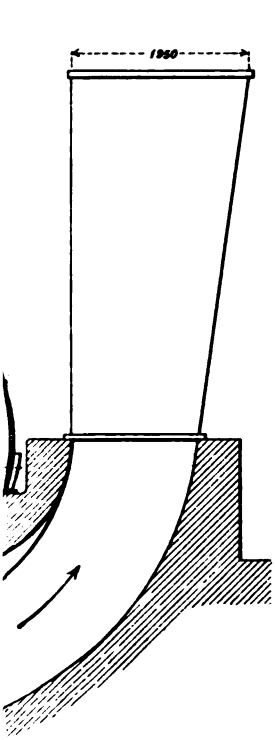
Fig. 125 c.
Shovel Form.



Rateau Fan (Fig. 125 a - c).

Fig. 125 b.





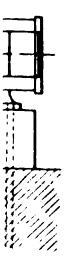
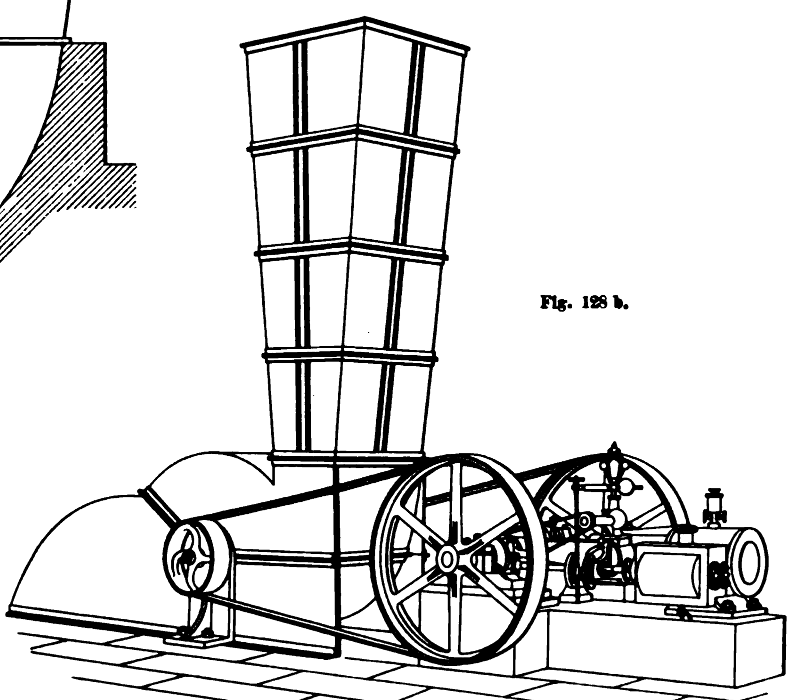


Fig. 128 b.



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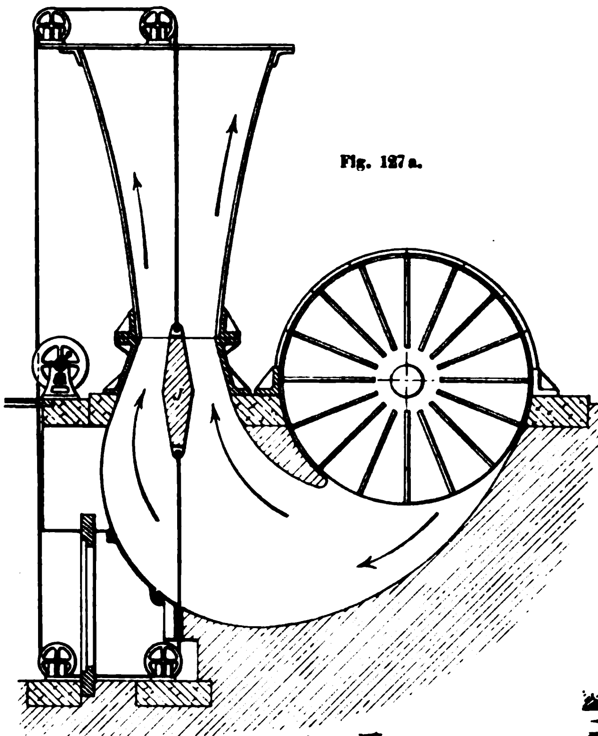


Fig. 127 a.

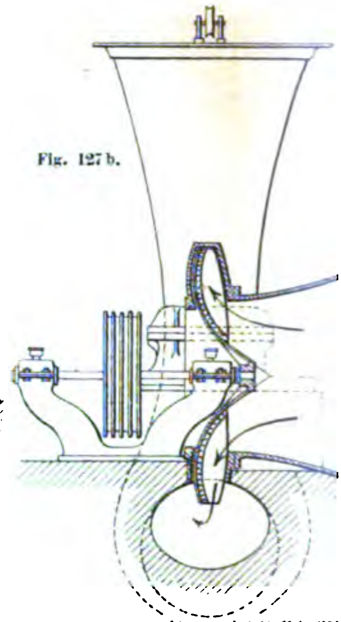


Fig. 127 b.

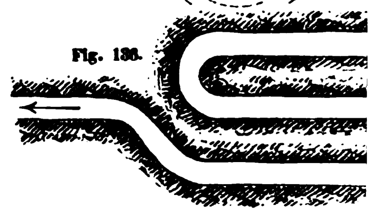


Fig. 136.

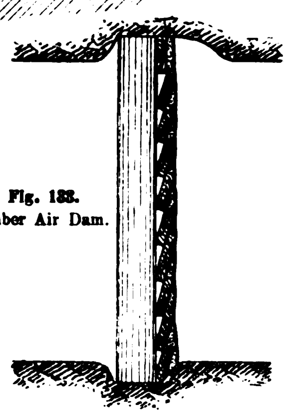


Fig. 133.
Timber Air Dam.

Fig. 134 a. Air door with sh

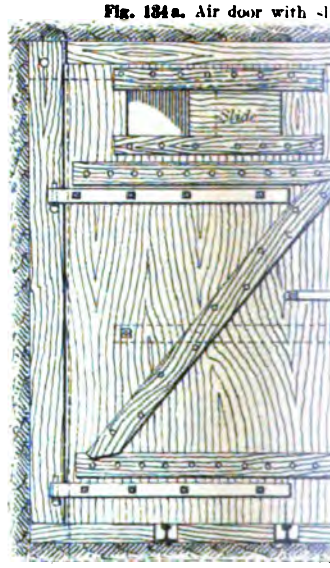


Fig. 132. Airway Crossing.

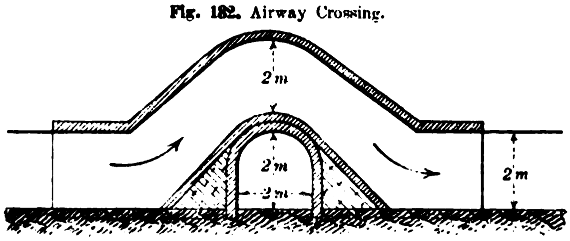


Fig. 130.

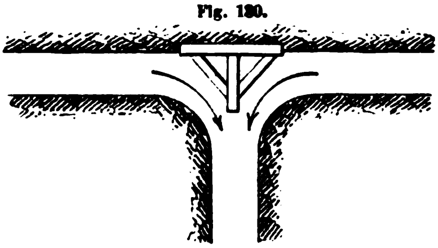
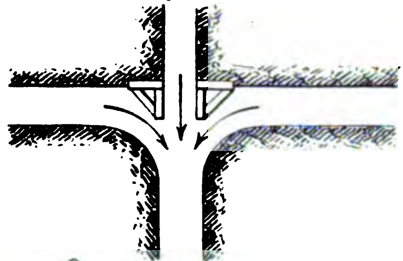
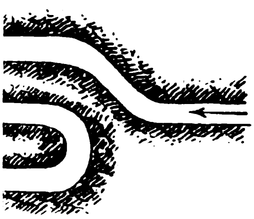


Fig. 131.





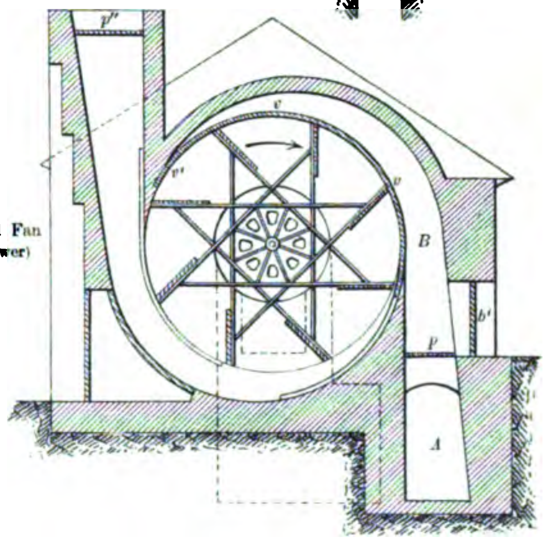


Fig. 129. Guibal Fan (exhaust or blower)

Fig. 134 b.

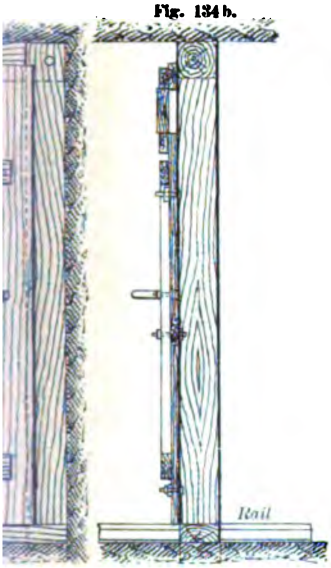


Fig. 135 a. Safety Door (after Guibal).

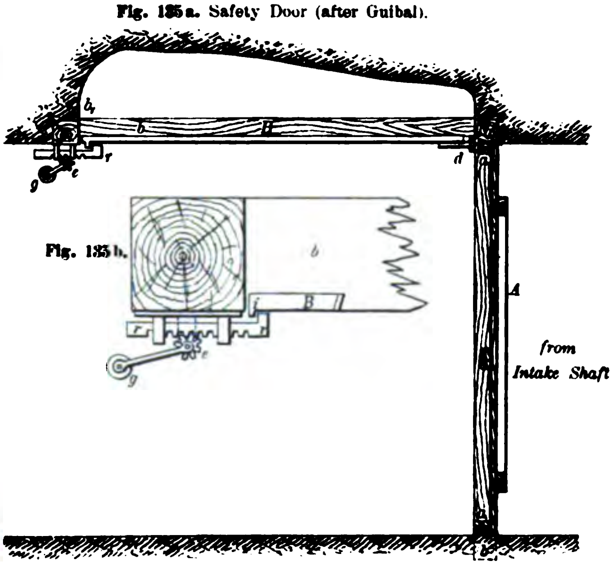


Fig. 135 b.

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Fig. 438 a. Plan.

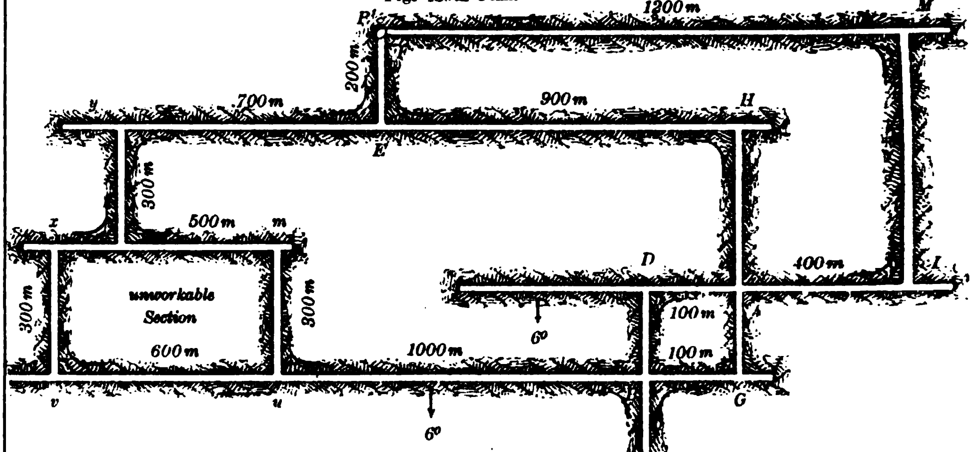


Fig. 440.

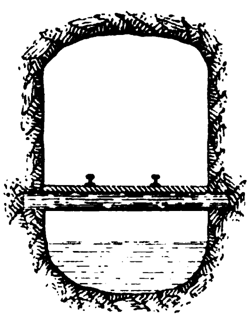


Fig. 141.

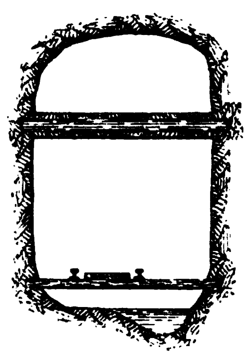


Fig. 439.

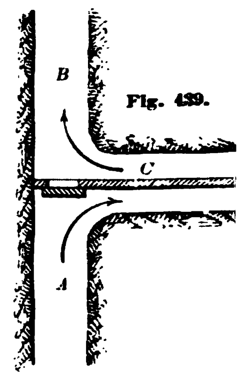


Fig. 442.

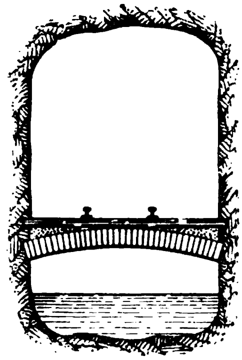


Fig. 143.

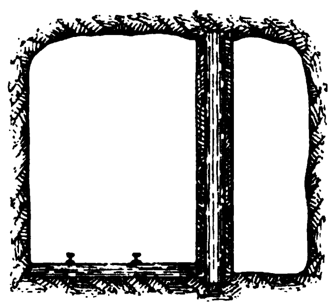


Fig. 14

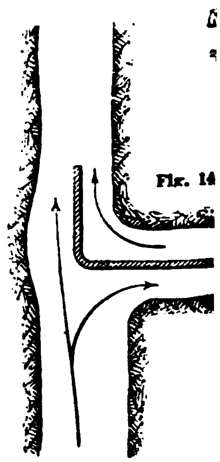
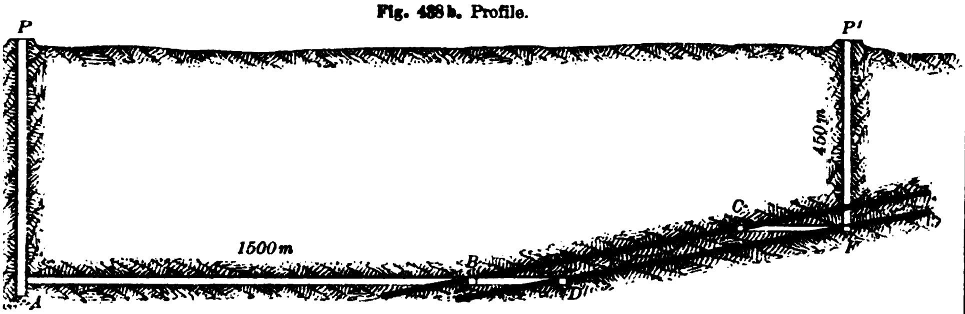
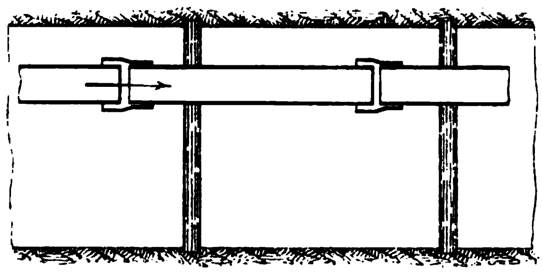
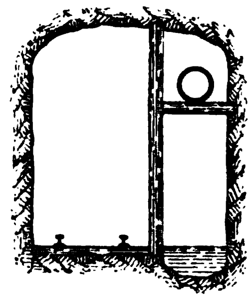


Fig. 488 b. Profile.







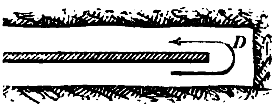


Fig. 147.

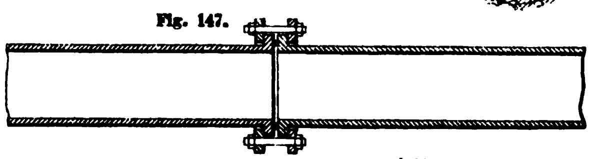
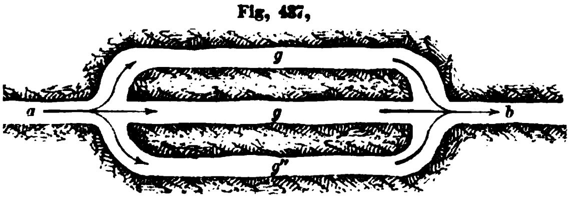


Fig. 487.



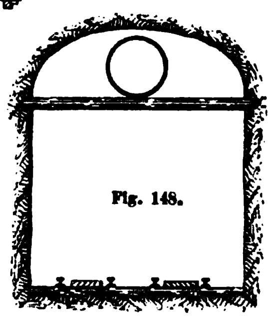


Fig. 148.

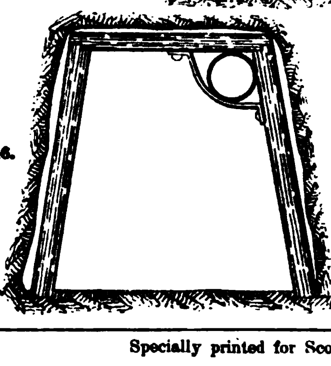


Fig. 146.

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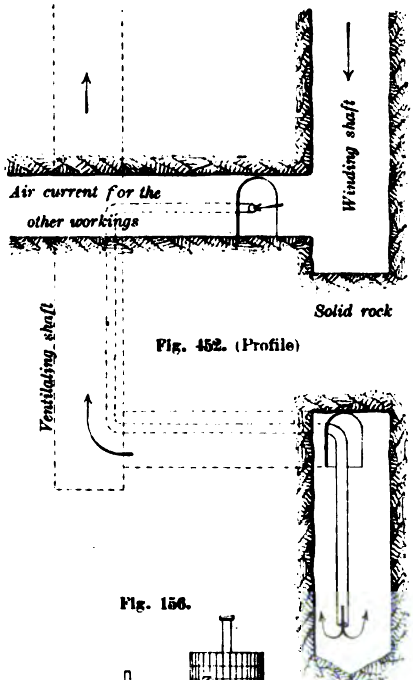


Fig. 152. (Profile)

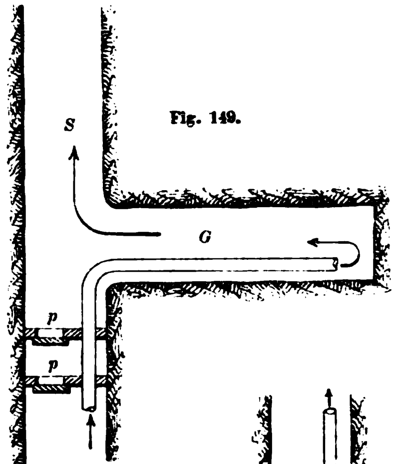


Fig. 149.

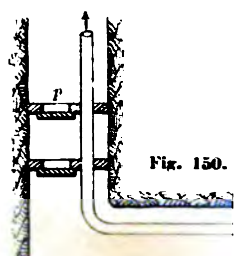


Fig. 150.

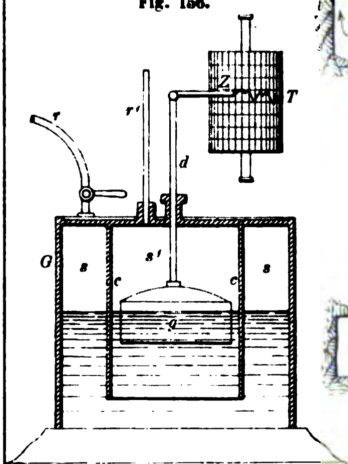


Fig. 156.

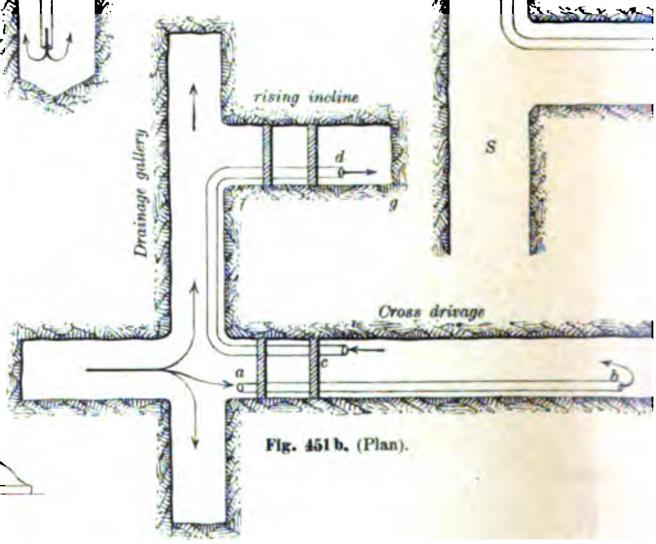
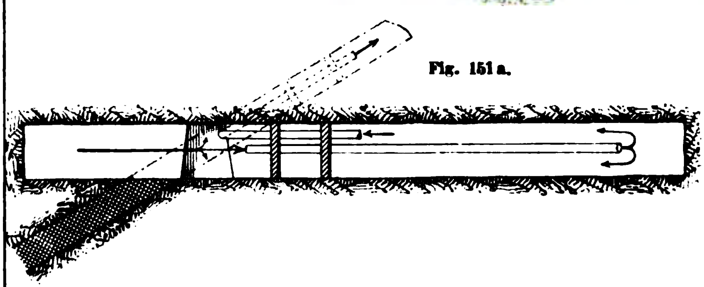


Fig. 151 b. (Plan).



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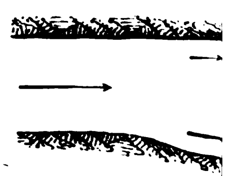


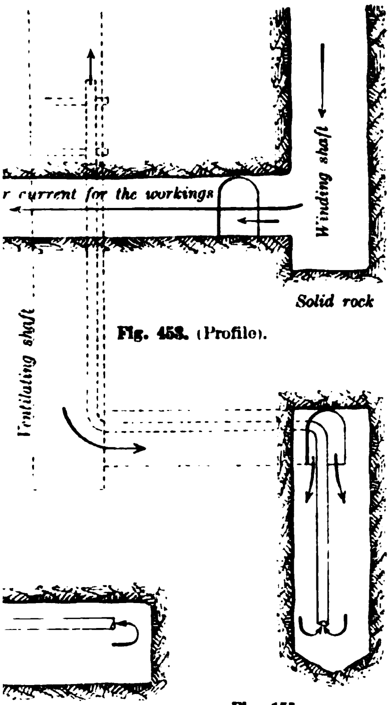
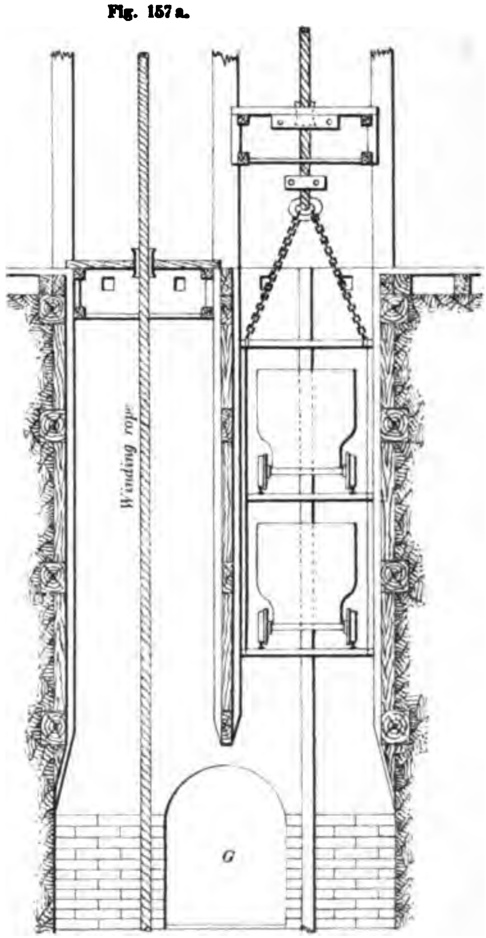


Fig. 153. (Profile).

Fig. 157 a.



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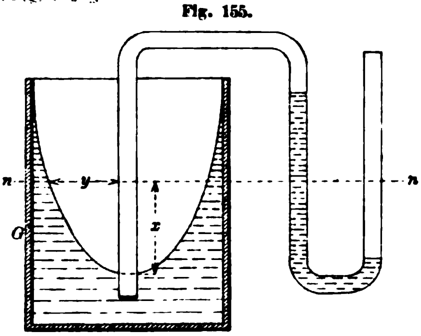
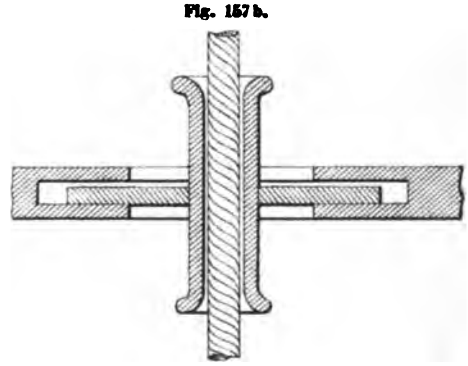


Fig. 157 b.



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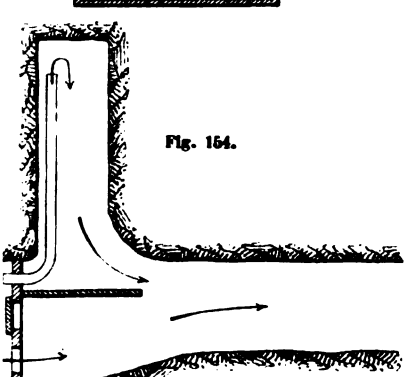

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